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STUDENTS

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MODERN PRACTICAL PHYSICS

(FOR INTERMEDIATE CLASSES)

By

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INTRODUCTION

General instructions for students working in a Laboratory

(1) To prevent unnecessary failures in experiments and consequent loss of time, never try to begin an experiment unless you have understood the *purpose of the experiment*, *i.e.*, grasped a clear idea as to what you are going to do. To accomplish this, it is necessary to come prepared with that experiment from your book *at home*. Attend carefully to the instructions that might be given to you by the teacher before the commencement of the experiment. Next collect the required apparatus and place them on the table at the seat assigned to you. Begin the experiment bearing in mind the precautions that you are to observe during its performance. See that everything is neat and clean. For a successful performance of the experiment you must try to acquire dexterity in manipulation.

(2) Make all your observations *carefully* with ease and comfort for if the readings are not taken conveniently the experiment is likely to be hurried over. See that any part of the apparatus requiring frequent manipulation or adjustment is placed within easy reach. There would then be a less chance of accidentally deranging the apparatus.

(3) Record your observations in your note book directly they are taken. **Scraps of paper for recording preliminary observations should be avoided.** Let it not be considered that by writing wrong observations the page of your copy book is "spoiled". If, however, a wrong observation is recorded do not try to erase but correct it simply by scoring through as ~~38·62~~, and the correct entry made above or below it.

Do not try to make your calculations long and tedious, but try *always to use the Logarithmic Tables*. In the few cases when it is simple to multiply or divide, use the ordinary methods of multiplication or division.

(4) Enter the observations directly as they are made. Do not try to "cook" the results. It has often been seen that the students in trying to get good results put down observations and measurements which were never made. They juggle with figures and calculate in a manner which clearly betrays their dishonesty.

(5) Make all your measurements with great care and accuracy and try to estimate the smallest possible division where necessary. For instance if your scale reads millimetres, estimate the tenths of a millimetre carefully.

If an observation gives the quantity equal to a whole number of units and the measurement can be made to tenths or hundredths, put down the decimal to show that the measurement was accurate to tenths or hundredths as the case may be. Suppose the length of an iron cylinder measured by a metre rod graduated to a millimetre is found to be exactly 12 cm., you should not express the result as such, but put 12·00 cms. to show that you did not neglect the millimetres or their tenths.

(6) Do not try to make your table dirty nor allow water, mercury, and other chemicals to come in contact with the metal parts of the apparatus. Wipe off with a wet duster the apparatus so soild and smear it with vaseline.

(7) After finishing the experiment, leave the apparatus neat and tidy. Throw off water and other liquids into the sink. Present your note book to the teacher in charge who after signing your experiment (if correct) will assign to you a new experiment for the next turn.

(8) Do not sit, lean, or scribble on your working table or walls of your laboratory. Avoid meddling with switches and taps. Report voluntarily all breakages or losses. Do not wait to be detected.

Calculations of Results.—(*a*) Do not try to make your calculations unnecessarily long. How many decimal places should be given depends upon the accuracy of the data from which the result is calculated. It has often been seen that the students carry out their results to seven or eight places of decimals when probably the result is not accurate to third place. If you have expressed your quantities to the last

figure to which you could accurately measure, then in the result you calculate, you should not have more significant figures than what they are in the quantity which contains the smallest number of figures. For example if we determine the volume of a cylinder 2·37 cms. long and 1·13 cm. in diameter it is given by $\pi\left(\frac{1\cdot13}{2}\right)^2 \times 22\cdot37$ c.cs. The volume of the cylinder on arithmetically working it out comes out to be 2·3768191062 but should be expressed as 2·37 c.cs., because our measurements of quantities is correct to three figures only and we have no right to express the result to more than three figures. If in the determination of specific gravity we weigh in air and water upto ·01 gm. *i. e.*, to two places of decimals and the loss of weight in water is 3·10 grams then the result cannot be more accurate than three figures.

(*b*) It is very important that ***we must measure the quantities very accurately which have to be squared or cubed in calculations.*** Take the mean of large number of observations of such quantities.

(*c*) In most cases before performing the accurate calculations ***approximate calculations should be made in order to avoid large errors.*** Suppose we want to find out the volume of the cylinder from its dimensions.

From approximate calculations the volume is of the order 3 c.cs. If the results had come out to be ·3 c.cs. it would be evident that there was some large error in the calculation *i. e.*, mistake in fixing up the decimal.

(*d*) Estimate your accuracy in terms of percentages and significant figures. The correct value of g at Lahore is 976 cms./sec^2 and if we get the result as 1000, the percentage error would be $\frac{24\times100}{976}=2\cdot5$ (nearly).

(*e*) More attention should be paid to the **weakest spot** of the experiment. This is the part where for various reasons either accurate measurements are not possible or where unusual accuracy is necessary in order to secure a moderate degree of accuracy in the final result.

Errors in Physical Measurements. Students should note that they should not feel dissatisfied if their different observations do not exactly tally. Complete coincidence in our observations is almost out of question because a large number of errors called the errors of observations are bound to occur and affect our results in the practical class. The following are a few of the usual types of errors the student will come across while working in the laboratory.

(1) **Errors of observation.** These will affect the true value of the physical quantity both positively and negatively. These may be greatly reduced by taking a very large number of independent measurements of the same physical quantity and then taking their mean *i. e.*, it is the sum of series of observations divided by their number and may be represented by the formula $\frac{a+b+c+d\ldots\ldots \text{ to } n \text{ terms}}{n}$ when there are n observations. The arithmetic mean is therefore more accurate than most of the individual observations.

Mathematicians tell us that the arithmetic mean is the best representative value of a series of discrepant observations."

(2) **Accidental Errors :—**

Errors creeping into the results from unknown sources or in uncontrollable ways. These are avoided, for the most part, by taking the mean of repeated observations of the **same thing.**

(3) **Constant or Systematic Errors :—**

These errors cannot be got rid of by any amount of repitition of observations. They are due to some source of repetition of observations. They are due to some source of constant error *e. g.*, the inaccuracy of a merte scale with which lengths are measured, the shifting of zero point of a screw-gauge, or a spherometer, the inequality of the arms of a balance, the alteration in the volume of the bulb of a thermometer after it has been graduated. These are then known as the instrumental errors.

These errors can be eliminated by taking observations with *efficient instruments* and under *different conditions.* Thus a barometer, a thermometer or a stop-watch can be compared with correct instruments. In the case of a faulty

metre-stick, readings should be taken from different points on it.

(3) **Personal Errors.**—These errors depend upon the personal habits of a person. No two persons can read, see or hear alike. While using a stop-watch for noting time no two persons will have concurrent readings. Similarly while reading a burette an observer may read too high and another too low. No set rule can be given for the elimination of such errors. The personal equation is different for different individuals. Such errors can be removed by taking care about your work.

(4) **Proportional Errors.**—Such errors occur when we cannot measure directly the quantities involved but can calculate them from those that can be measured. Thus in the calculation of the volume of a cylinder, the radius of the cylinder must be measured more accurately than its length because the radius is squared.

NOTE BOOK

Buy always a note book which should have some graph papers attached to it because in Physics we often want to represent some quantities graphically. The left hand pages of your note books should be used while you are in your practical class.

Record the following in pencil on the *left hand page* :—

(1) The date of the experiment.
(2) The name of the experiment.
(3) A list of the apparatus required.
(4) Observations (giving quantities and their names).
As far as possible record your observations in a tabular form.
(5) Calculations.
(6) Sketch of the apparatus (if possible).
(7) Precautions.

On the *right hand page* write in ink the following :—

(1) The date of the experiment.
(2) The name of the experiment.
(3) *The method and manipulations in a concise and narrative form.

*This may either be entered on the same page ...

(4) Sources of errors.

Specimen of a left hand page in pencil. (*Laboratory Record*). Dated. 4th Jan. 1934.

Experiment. **To determine the velocity of sound in air at the room temperature.**

Apparatus.—Resonance tube with a glass jar, fitted to a stand, a tuning fork with a cushion pad, a metre rod with stand, plumb line, a set square and a vernier calipers.

Observations.

Frequency of the tuning fork =
Temperature of the room =......°C.
Diameter of the tube in transverse position =(1)...(2)......
Mean=......cms.

No. of observations.	First Resonance.		Resonance column (l_1)	Second Resonance		Resonance column (l_2)
	open end	Water level.		open end.	Water level.	
	cms.	cms.	cms.	cms.	cms.	cms.
column increasing 1						
2						
3						
column decreasing 4						
5						
6						

Mean l_1=...... Mean l_2=......

Calculations and Results.

End correction (c)= $3\times$diameter= cms. (say)

1. **Velocity.** Let Velocity at room temperature=V cms.

(*a*) From first resonance position.

$V = n \times \lambda$

$= 4n(l+c)$ cms. per sec., where c is the end correction.

$= 4n(l+c) \times \cdot 01$ metres per sec.

(*b*) From 1st and 2nd resonance positions,

$V = 2n(l_2 - l_1)$ where l_2 is the second resonance poin ank l_1 the first resonance point.

$= 2n(l_2 - l_1) \times \cdot 01$ metres per sec.

Precautions

(1) The tube and the scale kept vertical, and se squares used for taking readings. Taken readings correc to half millimetre.

(2) End correction calculated from diameter and allow ed for in first formula, or eliminated by using the secon formula.

(3) Readings of the water level taken at the low surface, by keeping eyes at the same level.

(4) Three readings each for the column taken, whe increasing the length and when decresing it.

(5) Velocity is expressed in metres per second. Whe calculating frequency, velocity is expressed in cms.

(6) Struck the tuning fork at the end so as to avo overtones.

Specimen of the right hand page (*in ink*)

Dated, the 4th January 19

Experiment.—**To determine the velocity of sound air at room temperature.**

Apparatus.—Resonance tube with a glass jar, fitted a stand, a tuning fork with a cushion pad, a metre r with stand, plumb line, a set square and a vernier calipers

Method. I fitted the tube to the stand as shown in t opposite figure and filled the jar with water. The tuning fo after being struck against the pad was held with the rig hand of the mouth of the tube in the longitudinal positi (edgewise). With the left hand the length of the tube w gradually increased so that the sound heard becomes th

ance column. Again the tube was fixed to the stand and the readings were obtained by first increasing its effective length and then decreasing it. I changed the length of small amounts (one m.m. or two) when it was near the proper position. The tube being long enough the second position of resonance was similarly obtained and the readings were recorded in a tabulated form as given below. While taking readings the tube was kept vertical with the help of plumb lines and the readings were taken by sliding the set-squares along the vertical metre scale in the usual manner. The end correction was determined either by taking readings with calipers of the internal diameter of the tube or was eliminated by taking the two resonance positions.

Result.

Sources of Error :—

(1) The measurement of the length would be wrong, (*a*) for non-verticality of the tube (*b*) for, wrongly striking of the tuning fork.

MECHANICS

CHAPTER I

CONTRACTED METHODS OF CALCULATION AND LOGARITHMS AND THE USE OF LOGARITHMIC TABLES

Contracted Methods of Calculation. Students who are unfamiliar with logarithms often waste lot of time in calculations. They multiply and divide and retain more significant figures than are actually needed in the experiment. For their convenience, contracted methods of calculation are used as given below :—

Multiply $4895693 \times 31 \cdot 4896$.

Before proceeding with the method we shall give certain rules which must be grasped.

Rule 1. Shift the decimal after the first digit in every number of the expression to be computed and then to keep the meaning the same we multiply the whole by the proper power of 10. For instance the above two numbers $4895693 \times 31 \cdot 4896$ can be put down as $4 \cdot 896 \times 10^6$ and $3 \cdot 149 \times 10$ respectively.

2. To show the result correct upto 4 significant figures retain not more than 4 significant figures and if the digit after the 4th is greater than 5 the fourth digit should be increased by one and reject all digits after the fourth. If the fifth digit is less than 5 reject it, keeping the fourth unchanged.

3. Take the number having the simpler and repeated digits as the multiplier. Write down the multiplicand as it is and the multiplier (as given below in the method) in the two rows one below the other and draw the usual horizontal line. Draw also a vertical boundary line from it straight downwards.

Method. Place the unit figure of the multiplier under the fourth (marked) digit of the multiplicand and set down

all the other digits of the multiplier in the reverse order. Insert zeros if necessary so that every figure of the multiplier may have a figure above it. Place the partial products with their right hand digits under one another; add them and mark off from the right 3 places for decimals. If there are four figures in all in the product, this is the approximate answer to four significant figures. But sometimes as in the example below we get five figures. In such a case the figure adjacent to the vertical line should be neglected if it is less than five. If five or more than five, then add one to the fourth (next) figure and omit the fifth.

```
  4·8 9 6 |
  9 4 1 3 |
  ------- |
1 4 6 8 8 |
    4 9 0 | =489×1 plus 1 for 6×1=6
    1 9 6 | = 48×4 plus 4 for 9×4=36
      4 3 | =  4×9 plus 7 for 9×8=72
  ------- |
1 5·4 1 7 |
```

Result$=15{\cdot}417\times10^7=1{\cdot}542\times10^8$

Contracted division.

Divide ·06862368 by 723·7362.

This may be put down as

Divide $6{\cdot}862\times10^{-2}$ by $7{\cdot}237\times10^2$.

Rule. 1 Shift the decimal point in the divisor so that it may have one integral figure and make the compensating change in the dividend.

2. Ascertain by inspection the number of integral figures in the quotient. This number plus the required number of decimal places gives the number of significant figures in the quotient.

3. Proceed with the division in the ordinary way except that at each stage instead of bringing a new figure from the dividend reject a figure from the right of the divisor, remembering however on multiplication to add the nearest ten from the multiple of the digit last rejected.

Thus 7237) 6862(·948
65133
3487
2895
592 $=723\times4$ plus 3 carried from $7\times4=28$
578
14 $= 72\times8$ plus 2 carried from $3\times8=24$

Result$=\cdot948\times14^{-4}$

This may be put down as $9\cdot48\times10^{-5}$.

Common Logarithms. To reduce the often tedious and complicated processes of multiplication and division, square root, cube root etc., to the simpler and easier processes of addition and subtraction, the principle of logarithms has been introduced.*

Definition. We know that $10^2=100$, $10^1=10$, $10^0=1$, $10^{-1}=\cdot1$ and $10^{-2}=\cdot01$. We may write these relations in a different way.

(1) 2=logarithm of 100 to the base 10
(2) 1= ,, ,, 10 ,, ,, ,,
(3) 0= ,, ,, 1 ,, ,, ,,
(4) −1= ,, ,, ·1 ,, ,, ,,
(5) −2= ,, ,, ·01 ,, ,, ,,

In general, let $a^x=M$;

x is said to be the logarithm (in short, log) of a number M to the base a. **In Common Logarithms** the base taken is 10.

From the above it is evident that in (1) and (2) the logarithm of a number lying between 10 and 100 is positive and is greater than 1 but less than 2. For numbers between 10 and 100 the logarithm has therefore an integral part and a fractional part. Similarly for numbers greater than 1 and less than 10, the log is always positive and lies between 0 and 1, *i.e.*, it is always a fraction, or its integral part is zero.

***Note.**—At first the consultation of Logarithmic tables by the student appears to be tedious, and is not free from serious mistake. But on practice he will always find them useful and convenient.

The integral part of a logarithm is called the **characteristic,** while its fractional part is known as the **mantissa.** The latter is always expressed in decimal.

To find the characteristic of the logarithm of a number.

Rule. For a number greater than 1, the characteristic of its logarithm is always positive and is one less than the number of significant digits in the whole number part of it.

From relations (3), (4) and (5) it is clear that for a number less than 1, or for a fraction, the logarithm has always a negative characteristic. For a number less that 1 and greater than ·1, the characteristic of its logarithm is negative and is—1. *i.e.*, a number one more than the number of zeros after the decimal. Similarly for numbers between ·1 and ·01, the characteristic is negative and is—2, *i.e.*, a number one more than the zeros after the decimal.

Rule. In the logarithm of a number less than 1, the characteristic is always negative and is a number numerically one more than the number of zeros after the decimal.

The characteristic of the logarithm of a number can thus be written by inspection only and it depends on the number of significant digits before the decimal or the number of zeros after the decimal. It is either positive or negative. The negative (—) sign is generally put above the digit, and is called the 'bar' for example $\bar{1}$=one bar, $\bar{2}$= two bar, etc.

To find the mantissa of the logarithm of a number.

Rule. The mantissa or the fractional part of the logarithm of a number depends only on the significant digits in the number and is independent of the position of the decimal in it. We shall prove this rule later.

It is always difficult and tedious to calculate the mantissa. It is calculated for all numbers generally up to four figures and the results are given in the form of tables called the **Logarithmic Tables.**

In order to consult the logarithmic tables for finding the mantissa, we ignore the position of the decimal in the

number. In the first column of the tables are given the numbers 10 to 99. In front of these numbers are written the mantissa in four figures (supposed to begin with a decimal which is generally omitted), under the heads marked 1 to 9. After these are rows of numbers given under heads 0 to 9 in columns called the "difference columns". For a number consisting of four significant digits, find the first two digits in the column of numbers, and pass on in the same row. Under the head of the third digit in the number is the mantissa of the number consisting of the first 3 digits or of the number with 0 in the fourth place.

Find the fourth digit in the heads of the difference columns and add the number given below it in the same column and against the number, to the digit in the fourth place of its mantissa.

Example. Find the logarithm of the number 34·56.

The number consists of two digits before the decimal or the whole number part of it, hence the characteristic of its logarithm is 1. It is +1, because the number is greater than 1.

For the mantissa consult the tables. Ignore the position of the decimal, and in the first column find the number 34. In the row of this number and in the column under the head 5 is the number 5378. In the same row under the difference column marked 6 is the number 8. Add this 8, to the digit in the fourth place of the mantissa and we get the number 5386 which is, therefore, the mantissa of the logarithm of 34·56.

The characteristic is +1 and therefore the logarithm of the number is 1·5386. The sign of plus (+) is generally omitted.

The following rules are useful in finding the product or the quotient of two numbers with the help of the logarithmic tables :—

(1) $\mathrm{Log}_a(M \times N) = \log_a M + \log_a N$, where M and N are two numbers.

Let $M = a^x$, and $N = a^y$, or $x = \log_a M$ and $y = \log_a N$,

$M \times N = a^x \times a^y = a^{x+y}$.

or $\mathrm{Log}_a (M \times N) = x + y$.

Hence $\mathrm{Log}_a (M \times N) = \log_a M + \log_a N$.

Rule. Logarithm of a product of two numbers is the sum of the logarithms of the numbers.

Similarly $\text{Log}_a(L\times M\times N)=\text{Log}_a L+\log_a M+\log_a N$

(2) $\textbf{Log}_a \dfrac{\mathbf{M}}{\mathbf{N}}=\mathbf{log}_a\mathbf{M}-\mathbf{log}_a\mathbf{N}.$

Let $M=a^x$, $N=a^y$ or $\log_a M=x$ and $\log_a N=y$.

$$\frac{M}{N}=a^{x-y}$$

Hence $\log_a \dfrac{M}{N}=x-y=\log_a M-\log_a N.$

Rule. Logarithm of the quotient of two numbers is the difference of the logarithms of the numerator and the denominator.

(3) $\textbf{Log}_a\,(\mathbf{M})^{\mathbf{P}}=\mathbf{P}\log M.$

Let $M=a^x$, or $\log_a M=x$.

$$(M)^P=(a^x)^P=a^{Px}$$

Hence $\log_a(M)^P=Px=P\log_a M.$

Rule. Logarithm of a number raised to the power P is the product of P and the logarithm of the number so raised.

To find the number from its Logarithm.

The number corresponding to a given logarithm is called its **anti-logarithm**. To find a number from its logarithm, anti-logarithm tables are used.

The mantissa only of the logarithm of a number determines the significant figures in the required number. The characteristic of the logarithm determines the position of the decimal, and is, therefore, omitted in consulting the table for finding the required number.

The first column of the anti-logarithm tables contains mantissæ from ·00 to ·99. Against these are rows of numbers consisting of four digits, under the heads 0 to 9, and as in the case of the logarithmic tables the fourth digit of the mantissa is found under the heads of the difference column. The number under this head and in the row against the first

two digits of the mantissa is added to the fourth digit of the corresponding mantissa and we get the significant digits in the number.

The characteristic of the logarithm determines the position of the decimal in the number, as explained under the rules for finding the characteristic of a number.

Examples. Find the anti-logarithm of 2·8158 or the number whose logarithm is 2·8158.

We first take the mantissa ·8158. In the row against ·81, and in the column under the head 5 is the number 6531. To the fourth digit of this add the number 12 occurring in the same row and under the head 8 in the difference column. This gives 6543, the significant digits in the required number.

To locate the decimal, we have 2 as the characteristic, and therefore the whole number part of the number consists of three digits or the number is 654·3.

To show that only the mantissa of the logarithm of a number determines the significant figures in the number.

Example. Log $1 \cdot 234 = 0 \cdot 0913$.

1. Show that $\log 1234 = 3 \cdot 0913$.

We have $1234 = 1 \cdot 234 \times 1000$.

$\log 1234 = \log 1 \cdot 234 + \log 1000$.

But $\log 1000 = 3$, the mantissa being 0.

$\therefore \log 1234 = 0 \cdot 0913 + 3 = 3 \cdot 0913$.

2. Show that $\log \cdot 01234 = \bar{2} \cdot 0913$.

We have $\cdot 01234 = 1 \cdot 234 \times \dfrac{1}{100}$.

$\log \cdot 01234 = \log 1 \cdot 234 + \log \dfrac{1}{100}$

$\log \dfrac{1}{100}$ or $\log \cdot 01 = \bar{2}$. $\therefore \log \cdot 01234 = 0 \cdot 0913 + \bar{2} = \bar{2} \cdot 091$

It is obvious from the above that the mantissa of th logarithm of a number depends solely upon the significan digits in it and *vice versa*. It is also always positive. If th characteristic happens to be negative, the mantissa and th characteristic of the logarithm should be separately treat when multiplying or dividing them by a number.

Example 1. Using log tables find the value of :—

(*i*) $23{\cdot}51 \times 6{\cdot}78$, (*ii*) $23{\cdot}51 \div 6{\cdot}78$.

(*iii*) $\sqrt[3]{23{\cdot}51}$ (*iv*) $(6{\cdot}78)^{2{\cdot}34}$,

(*v*) $({\cdot}678)^{-1{\cdot}301}$. (*D. U. 1930*)

(*i*) Log $23{\cdot}51 = 1{\cdot}3713$
Log $6{\cdot}78 = 0{\cdot}8312$

By addition $2{\cdot}2025$

Anti-log $2{\cdot}2025 = 159{\cdot}4$.

(*ii*) Log $23{\cdot}51 = 1{\cdot}3713$
Log $6{\cdot}78 = 0{\cdot}8312$

By subtraction $0{\cdot}5401$

Anti-log $0{\cdot}5401 = 4{\cdot}868$.

(*iii*) Log $(23{\cdot}51)^{\frac{1}{3}} = \frac{1}{3}\log 23{\cdot}51$ [Log $23{\cdot}51 = 1{\cdot}3713$.

$= \frac{1}{3} \times 1{\cdot}3713$

$= 0{\cdot}4571$.

Anti-log $0{\cdot}4571 = 2{\cdot}865$.

(*iv*) $\log (6{\cdot}78)^{2{\cdot}34}$

$= 2{\cdot}34 \times \log 6{\cdot}78$; $\log 6{\cdot}78 = 0{\cdot}8312$

$= 2{\cdot}34 \times 0{\cdot}8312$; $\log 2{\cdot}34 = 0{\cdot}3692$
$\log 0{\cdot}8312 = \bar{1}{\cdot}9197$

$= 1{\cdot}945$ | by addition $0{\cdot}2889$
Anti-log $0{\cdot}2889 = 1{\cdot}945$.

Anti-log $1{\cdot}945 = 88{\cdot}10$.

(*v*) Let $({\cdot}678)^{-1{\cdot}301} = x$

$$\text{Log } x = -1{\cdot}301 \times \log {\cdot}678$$

$$= -1{\cdot}301 \times \log \frac{678}{1000}$$

$$= -1{\cdot}301\ (\log 678 - 3)$$

$$[\text{Log } 678=2{\cdot}8312] \qquad =1{\cdot}301 \ (3-2{\cdot}8312)$$

$$=1{\cdot}301\times{\cdot}1688={\cdot}2196$$

Anti-log $\cdot 2196=1{\cdot}658 \qquad \therefore\ x=1{\cdot}658$.

Example. 2. Find the value of

(*i*) $\sqrt[2]{\cdot 3142}$, (*ii*) $\sqrt[3]{\cdot 03142}$, (*iii*) $\sqrt[4]{\cdot 003142}$.

$$(i) \text{ Log } ({\cdot}3142)^{\frac{1}{2}} \qquad =\tfrac{1}{2}\times\log {\cdot}3142$$

$$[\text{Log } {\cdot}3142=\bar{1}{\cdot}4972] \qquad =\tfrac{1}{2}\times\bar{1}{\cdot}4972$$

$$=\tfrac{1}{2}(\bar{2}+1{\cdot}4972)$$

(On adding -1 to characteristic, to make it divisible by 2, and adding $+1$ to mantissa).

$$=\bar{1}{\cdot}7486$$

$$\text{Anti-log } \bar{1}{\cdot}7486 \qquad ={\cdot}5606.$$

$$(ii) \text{ Log } ({\cdot}03142)^{\frac{1}{3}} \qquad =\tfrac{1}{3}\times\log {\cdot}03142$$

$$=\tfrac{1}{3}\times\bar{2}{\cdot}4972$$

$$=\tfrac{1}{3}\times(\bar{3}+1{\cdot}4972)$$

$$=\bar{1}{\cdot}4991$$

$$\text{Anti-log } \bar{1}{\cdot}4991 \qquad ={\cdot}3156.$$

$$(iii) \text{ Log } ({\cdot}003142)^{\frac{1}{4}} \qquad =\tfrac{1}{4}\times\log {\cdot}003142$$

$$=\tfrac{1}{4}\times\bar{3}{\cdot}4972$$

$$=\tfrac{1}{4}(\bar{4}+1{\cdot}4972)$$

$$=\bar{1}{\cdot}3743$$

$$\text{Anti-log } \bar{1}{\cdot}3743 \qquad ={\cdot}2368.$$

Other examples will be found in the Text.

Note.—Sometimes it is very convenient to place the decimal after the first digit in every number of the expression to be computed because in that case the characteristic will be the same (*i.e.*, zero).

CHAPTER II

GRAPHS AND HOW TO PLOT THEM

Definition. *A graph* is a line, straight or curved, showing the relation between two variable quantities, whose values depend one upon the other. The quantity whose value depends upon that of the other is called the *Dependent variable* while the latter is known as the *Independent variable*. For example in Hooke's Law,

$$\frac{\text{Stress}}{\text{Strain}}=\text{constant}$$

$$\frac{F}{l}=k=\text{constant}$$

$$\text{or} \quad F=k\times l \quad \ldots\ldots(1)$$

where
F = stress,
l = strain.
k = constant.

where F, the force exerted upon unit cross-section of an elastic string, or the *stress*, is the independent variable ; and l the extension or elongation produced per unit length is the dependent variable. Similarly in Boyle's Law

$$p\times v=\text{constant}=k \ldots\ldots(2)$$

where
p = pressure,
v = volume.

The volume of a certain mass of a gas depends upon the pressure exerted upon it, the temperature remaining constant. The pressure (p) is the independent variable, while volume (v) is the dependent variable.

Or again in Ohm's Law,

$$\frac{E}{C}=R=\text{constant}$$

$$\text{or} \quad E=R\times C \ldots\ldots\ldots(3)$$

where
E = electro-motive force,
C = current,
R = resistance of a conductor.

The value of the current through a conducting wire depends upon the E. M. F. applied at its two ends. The current (C) is, therefore, the dependent variable and the E. M. F. (E) is the independent variable.

The equations (1), (2) and (3) represent relations between two quantities, whose variation can be best studied by means of graphs. We know from Co-ordinate Geometry that

$$y=mx+c \qquad \ldots\ldots(4)$$

represents a straight line, cutting the axis of x at an angle whose tangent is $=m$, and the axis of y at a distance c from the origin.

This equation is of the form of equations (1) and (3); $c=0$ and $m=k$

$$y=k\times x \qquad \ldots\ldots(5)$$

a straight line passing through the origin.

The above equations, therefore, can also be represented by straight lines.

Equation (2), which stands for Boyle's Law, is of the form

$$xy=\text{constant}=k$$

and it represents the curve called "rectangular hyperbola." This can, however, be put in the form of equation representing a straight line thus :—

Taking logarithms of both sides, we have

$$\log p+\log v=\log k=\text{constant}$$

$$\text{or} \quad x+y=c \quad \text{where}$$

$$\text{or} \quad y=-x+c \qquad \begin{cases} x=\log p, \\ y=\log v, \\ c=\log k. \end{cases}$$

This is of the form $y=mx+c$, as in the above. Or alternately,

$$p\times v=k$$

$$\text{or} \quad p\div\frac{1}{v}=k$$

$$\text{or} \quad p=k\times\frac{1}{v} \qquad \begin{cases} \text{If } y=p \\ \qquad x=\dfrac{1}{v}. \end{cases}$$

$$y=k\times x$$

This is of the form of equation (5).

We come to the conclusion, therefore, that if the ratio of the two variable quantities be constant, the equation represents the definite law for which it stands and can be represented graphically by a straight line. The two quantities are said to be in direct ratio to one another, or one directly proportional to the other. The equation is called a Linear Equation. If the product of the two quantities be constant, the question or the law, for which it stands, can be shown by a graph, which is part of the curve 'rectangular hyperbola.' The two quantities are then, in inverse ratio to one another, or one is inversely proportional to the other. The latter can, however, be put in the form of a relation bearing direct ratio, the graph is then a straight line.*

Let us now find out how we can show and study these laws graphically.

How to plot graphs.—Graphs are plotted on ruled paper on which two sets of parallel lines are drawn at equal distances and at right angles to one another so as to form squares. This is called graph paper or squared paper. The divisions are either in inches and tenths of inches or centimetres and millimetres. The smaller divisions are in fine thin lines, and the larger ones in bold thick lines.

The experimental data are, at first, collected in two parallel rows or columns. This is obtained throughout the whole range of the experiment and sufficient readings, never less than five, are taken for the two variable quantities, appreciably different from one another.

Two thick lines, at right angles to one another are selected near the bottom and the left-hand edge of the paper, as the axes of reference or the co-ordinate axes. The horizontal line is marked O—X and is called the X-axis and the vertical one marked O—Y is known as Y-axis. Distances measured along the X-axis are called the *abscissa*, and those measured along the Y-axis the *ordinates*. O, the common point on the two axes, is the *origin*. Arrowheads drawn along the two axes generally show the directions in which the distances are measured.

***Note.**—We generally deal with such simple graphs in experimental work. But there are other more complex relations which we shall discuss under examples.

The independent variable, or the quantity whose change we do not want to study, or in which we are little interested is shown along the X-axis while the dependent variable, or the quantity which is the subject of our study, or which interests us more is marked along the Y-axis. The two quantities are written down along the axes below the arrowheads.

If the quantities obtained are in decimal fractions, these are changed into whole numbers by multiplying them with suitable factors, *i.e.*, 10, 100, 1000, etc.

Such factors in the ratio will change only the constant involved and shall have no effect on the shape of the curve or graph. This is generally done orally to save time and the trouble of re-writing the quantities involved.

It is always advisable to draw as large a graph as possible in the space available on the paper. This is also desirable to show the relation more clearly. This requires a suitable choice of the units and the origin. This minimum or the smallest quantity or number, as the case may be, is subtracted from the maximum or the largest, and the difference is increased to the next higher round number having zero in place of unity. The number so obtained is divided by the largest number of large divisions, available along either axis, by which it is divisible. The quotient gives the quantity or the number to be represented by one large division, an inch or a centimetre. This is written along the two axes where the two quantities are shown. The smaller divisions, or tenths of inches or millimeters show one-tenth of this. It is, sometimes, convenient to raise the difference between the maximum and minimum quantities to a round number, which when divided by the number of larger divisions available gives a quotient with zero in the unit place. This will give a whole number and not a fraction to be represented by the smaller divisions.*

To obtain the largest possible graph, it is also necessary that the origin be taken to represent the quantity, or

---

***Note.**—On the choice of a proper unit depends the success or failure of the student to draw a good graph and it is here that his resourcefulness and ingenuity is taxed to the utmost. It is neither profitable nor possible to give hard and fast rules for this. A careful student will overcome his difficulties by drawing a few graphs by himself.

number, which is the next lower round number to the minimum quantity with zero in the unit place. The extreme point marked on the thick line near the right-hand edge of the paper, will then stand for the next higher round number to the maximum quantity.

In order to make it easy for plotting the various readings, it is better to mark the large divisions along the two axes with proper values, which may not be those included in the data.

The points on the X-axis corresponding to a reading of the quantity to be shown along it, is ascertained and from this we pass along the vertical line to a distance equivalent to the corresponding reading of the second quantity and mark the point by drawing a small circle round it by means of a cross. All other points are similarly marked.*

A glance at the series of points so plotted will at once show if the graph is to be a straight line or curve. In the first case with the help of the ruler draw a fine line, which passes nearly through all the points, being careful to see that it passes through the maximum number of points. If the points do not appear to lie in a straight line, they should be joined together by a smooth curve drawn either free hand or with the help of a flexible steel tape or clock spring. The curve drawn should not be jerky or zigzag and should pass through *nearly all* the points.

We shall now attempt to make the above points clearer by giving a few examples.

Example 1. Draw a graph for the densities of water at different temperatures from the following data :—

Temperature	0°C	4°C	8°C	12°C	16°C	20°C	24°C
Density	·99987	1·00000	·99988	·99953	·99897	·99823	·99732

***Note.**—In the earlier stages of the work it is neither useful nor easy for the student to try to represent by the smallest division on the graph the last significant digit in his observations showing in the graph the same accuracy as obtained in the performance of the experiment. This should be done wherever possible but it should not be insisted upon.

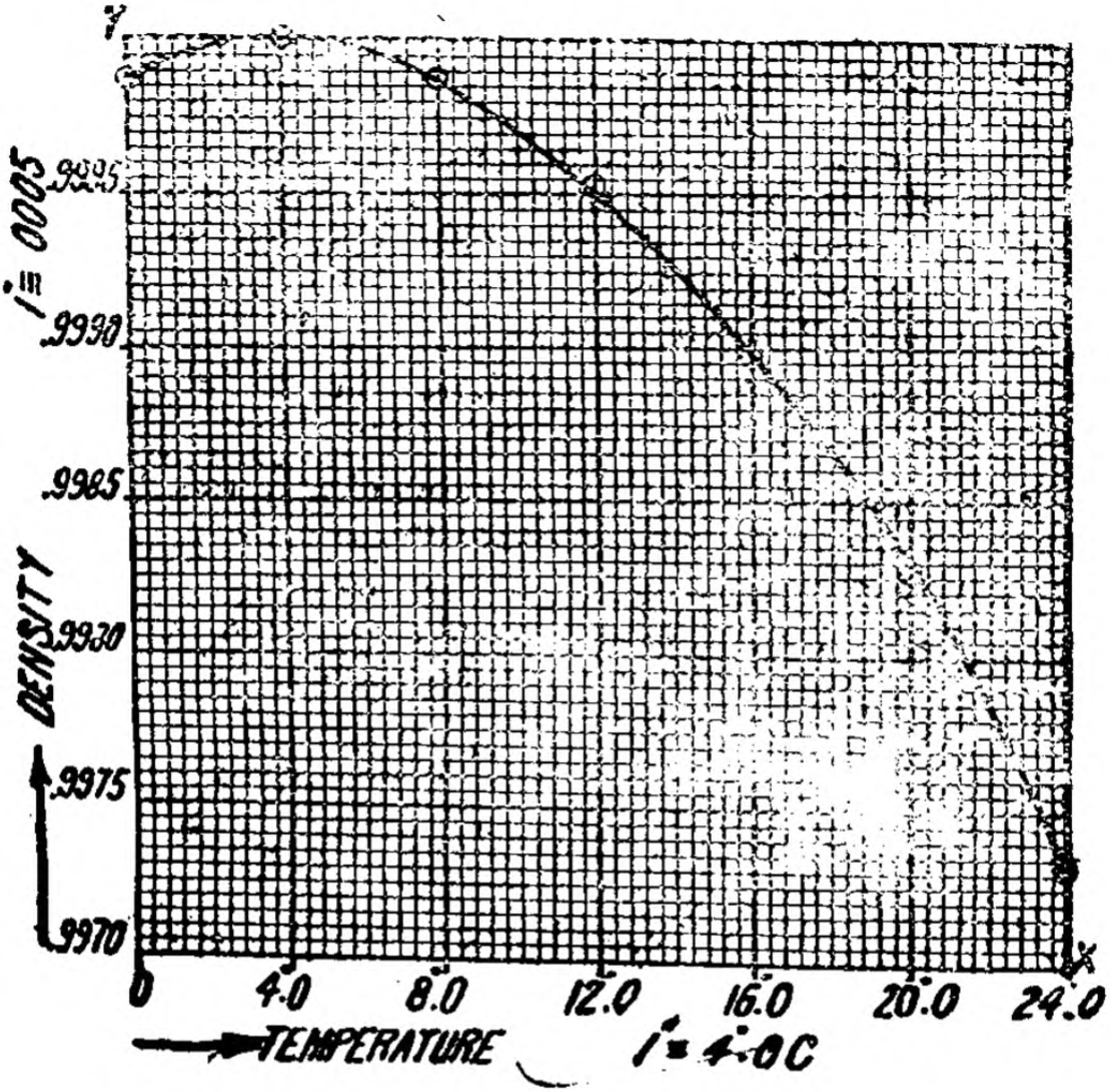


Fig. 1

We show temperatures along the X-axis and the variation of densities which we desire to study along the Y-axis. Refer to Fig. 1.

Taking the first thick line near the left hand edge of the paper as our axis of Y, let us say that there are six inches available along the axis of X. One inch can conveniently represent 4°C. The readings for the temperature are, therefore, marked as 0, 4, 8, 12, etc.

Convert the readings for the densities into whole numbers by multiplying them with 1,00,000 or by shifting the decimal five places to the right. The maximum number to be allotted is then 1,00,000 and the minimum 99,732. Their difference is (1,00,000 – 99,732) = 268. The next higher

round number with zero in the unit place is 270. Taking the lower-most thick line as axis of X, let us say that there are ten inches along the Y-axis. Dividing 270 by 10 we get 27 as the number to be represented by 1 inch. The smaller division will then represent 2·7. It is better to have 300 as the next higher whole number to the difference as the larger division will then represent 3, *i. e.*, 1″=·003 and 0·1″=·0003. This will then be the limit of accuracy shown by the graph. We do not start with zero as the origin but with ·99730.

The points are marked as shown in the graph and a smooth curve drawn through almost all of them.

The sharp bend in the curve shows clearly the anomalous behaviour of water when its temperature is raised.

Example 2. Draw a graph for the length l, and the periodic times t, of a simple pendulum from the following series of observations obtained in an experiment, and show that it is part of a Parabola :—

Obs. No.	1	2	3	4	5	6	7
l	18·88	34·21	49·32	64·86	80·43	95·45	110·78 cms.
t	0·87	1·17	1·40	1·61	1·80	1·95	2·10 sec.
t^2	0·75	1·37	1·37	2·59	3·22	3·81	4·43 (sec)^2

In order to show clearly that the graph drawn is of the form of a Parabola, we take origin as zero, both for the length and the time.

Let us say there are six large divisions, inches in this case, available along the X-axis and five and a half along the Y-axis. We show lengths as abscissæ and time periods as ordinates. The maximum length taken is 110·78 cms. ; but to suit our requirements and the space available on paper, we neglect the decimal part of it. The next higher round number divisible by 6 is 120. One inch can, therefore,

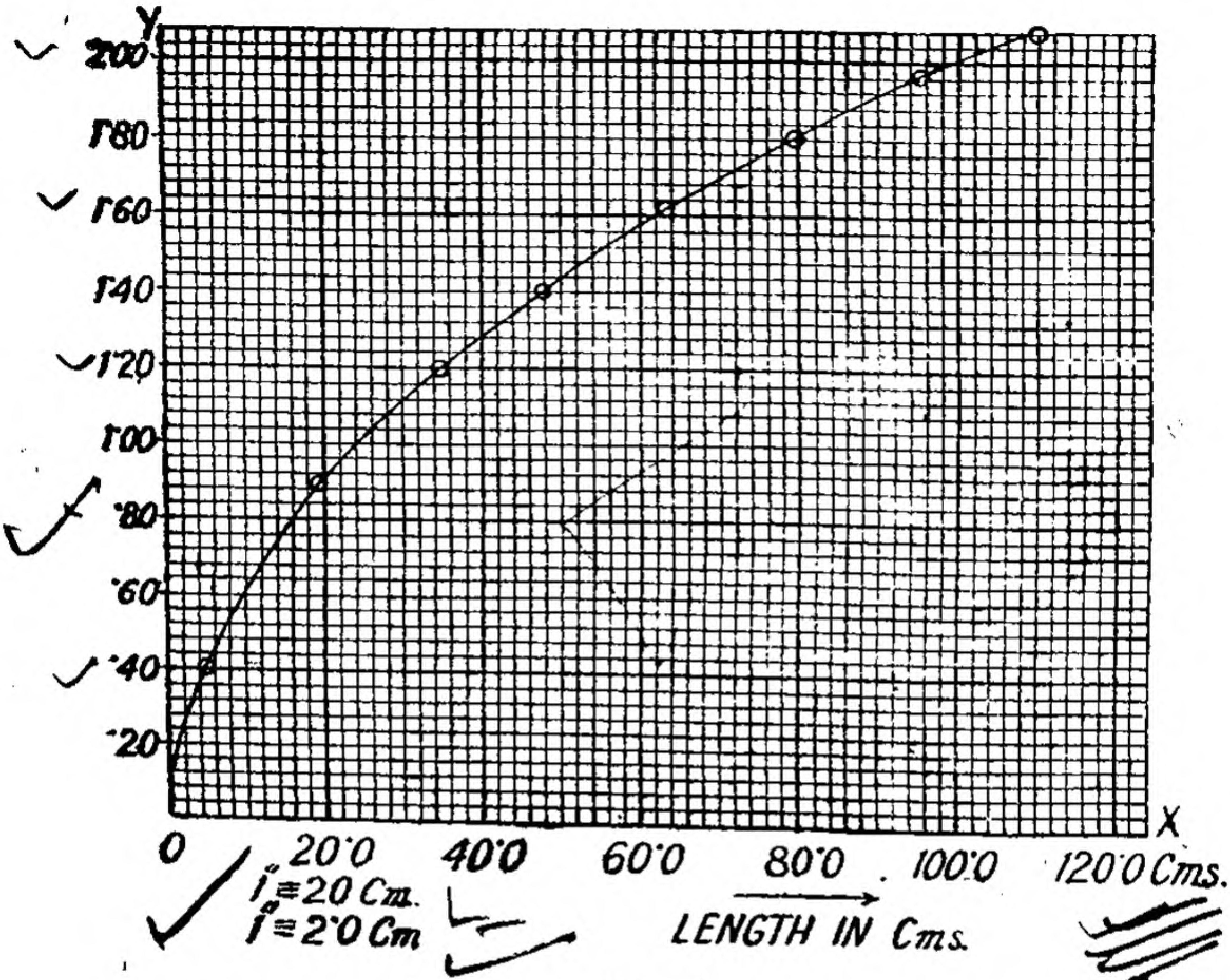


Fig. 2.

Ordinate ≡ Periodic time in seconds

Scale : $1'' \equiv \cdot 40$ sec.
$0 \cdot 1'' \equiv \cdot 03$,,

represent 20 cms. and we write along the abscissa $1'' \equiv 20$cms. The maximum value for time is 2·10 sec. Converting all readings for time into whole numbers we get 210 as the largest. The next higher round number divisible by 5·5 is 220. One inch, therefore, stands for ·40 or 0·4 sec. Along the Y-axis we note $1'' = 0 \cdot 4$ sec.

We next mark the inch divisions in lengths and half inches in seconds, and begin plotting the corresponding points in each reading. For locating the various points along the two axes it is convenient to note further the value of small divisions, *e.g.*, $0 \cdot 1'' \equiv 2$ cms. and $0 \cdot 1'' \equiv 0 \cdot 04$ sec.

After marking the points we draw small circles round them and draw a smooth and continuous curve passing through all or nearly all the points. It is not necessary that the curve should always pass through all the points plotted. Possibly some of our readings are wrongly plotted, or may be the divisions on the graph paper are not equally spaced.

For $l=0$, $t=0$, or the curve passes through the origin. The graph is obviously of the form of a parabola. Let us show this to be the case theoretically also :—

We have

$$g=4\pi^2\times\frac{l}{t^2}\quad\begin{cases} g=\text{acc. due to gravity,}\\ l=\text{length of pendulum,}\\ t=\text{periodic time.}\end{cases}$$

as 'g' has a definite value at the place of observations, 4 and π, being numbers are constant and the ratio

$$\left.\begin{aligned} &\frac{l}{t^2}=c=\text{constant}\\ \text{or}\quad &\frac{l}{t^2}=\frac{1}{k}\\ \text{or}\quad &t^2=k.l,\end{aligned}\right\}\quad \begin{aligned}&\text{Let}\\ &c=\frac{1}{k}\\ &\text{where } k \text{ is also a constant}\end{aligned}$$

$$\text{or}\quad y^2=kx\quad\begin{cases}\text{Put}\\ y=t\\ x=l.\end{cases}$$

This equation is of the form $y^2=4ax$, where $4a$=constant=latus rectum, which is the equation of a parabola with its vertex at the origin.

The graph showing the relation $\frac{l}{t^2}=c$ is, therefore, a Parabola.

Example 3. Plot a graph for l, the length and t^2, square of the period of the pendulum and obtain the value of the length of the Seconds Pendulum from it.

If t^2 instead of t is used, the relation $\frac{l}{t^2}=k$ can put in the form $\frac{x}{y}$=constant, where $x=l$, and $t^2=y$, which represents a straight line. To judge the accuracy of

eur results and to obtain either the mean value of $\frac{l}{t^2}$ for calculating 'g' or to get the value of l corresponding to $t=2$ sec or $t^2=4$, we generally plot the graph as a straight line.

Let us plot the values from the table given under example 2, omitting readings (1) and (2) for brevity. (Fig. 3) Let there be 7 in. along the X-axis and 5 in. along the Y-axis. The difference between the maximum and minimum value of the round numbers approaching the greatest and the least lengths is $110-40=70$. There being 7 in., 1 in. $\equiv$ 10 cms. To have the largest possible graph we take 40 cms. as the origin. The maximum for t^2 is nearly $4\cdot40-1\cdot90=2\cdot50$, or the whole number 250 is divisible by 5, the available divisions along the ordinate, or $1''\equiv0\cdot5$ and $\cdot1''\equiv0\cdot05$. The origin along this direction represents the number 1·90.

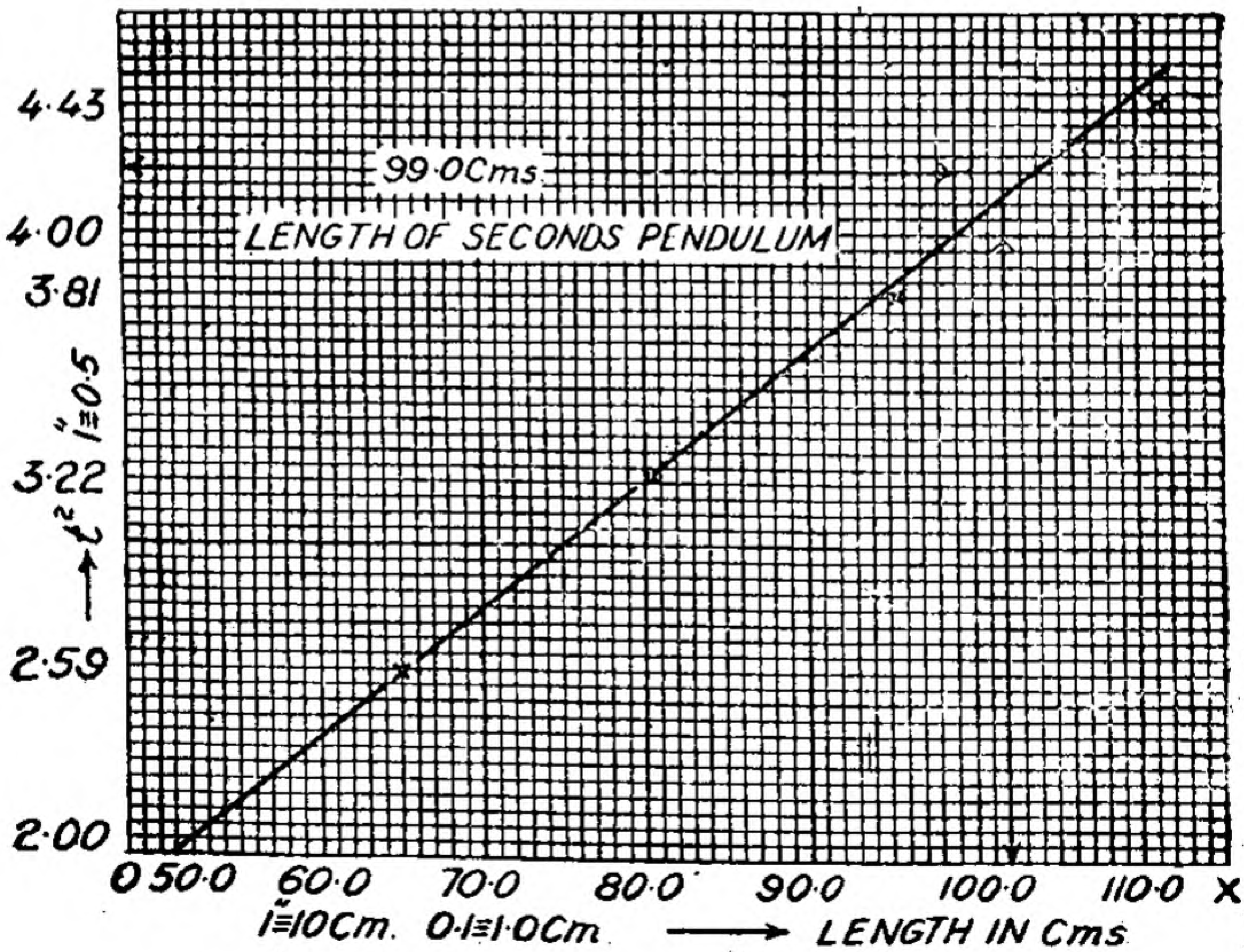


Fig. 3.

Scale : $1''\equiv0\cdot5$, $0\cdot1''\equiv0\cdot05$; Ordinate $\equiv$ Period^2.

After plotting the various points, we draw a straight line with a ruler which passes through as many points as possible, taking care that the points not falling along the line are equally distributed on both sides of it.

To evaluate 'g' from this graph, we choose any point on it and use the value of $\frac{l}{l^2}$ as obtained from the graph in our calculations. The corresponding value for $t=2$ sec. or $t^2=4$, is the length of the Seconds Pendulum, in this case 9·0 cms. nearly.

Example 4. An aeroplane is moving in a horizontal direction with a speed of 30 m. per hr. (44 ft per sec.). A bomb is dropped from the plane when it is at a height of 1,600 ft. Show by means of a graph that the path taken by the bomb during its downward journey is a Parabola.

$$S=ut$$
$$=44t$$

The value of S for $t=1, 2, 3, 4$ etc. sec. is as given below in the table :—

If S=horizontal distance covered by the plane in time t
u=44 ft. per sec.
=horizontal velocity
t=time

$$h=\tfrac{1}{2}gt^2$$
$$=16t^2$$

For $t=1, 2, 3, 4$ etc., h will be as follows :—

Also if h= vertical height through which it descends in time t.
g=acceleration due to gravity=32 ft per sec^2., t=time.

me	1	2	3	4	5	6	7	8	9	10 sec.
	44	88	132	176	220	264	308	352	396	440 ft.
	16		144	256	400	576	784	0124	1296	1600 ft.

The graph will be as shown in Figure 4.

Theoretically this can be shown thus : $\quad S = ut \qquad h = \frac{1}{2}gt^2$

or $\qquad t = \frac{S}{u} \;\; (1) \quad \therefore \; t = \sqrt{\frac{2h}{g}} \;\; (2)$

Eliminating *t* in (1) and (2), we get

$$\frac{S}{u} = \sqrt{\frac{2h}{g}} \quad \text{or} \quad \frac{S^2}{u^2} = \frac{2h}{g} \quad \text{or} \quad gS^2 = 2u^2h \quad \text{or} \quad S^2 = \frac{2u^2}{g}h.$$

For $S = y$, $h = x$, $2u^2/g = 4a =$ latus rectum $=$ constant $\therefore y^2 = 4ax$, which is the equation of a parabola passing through the origin.

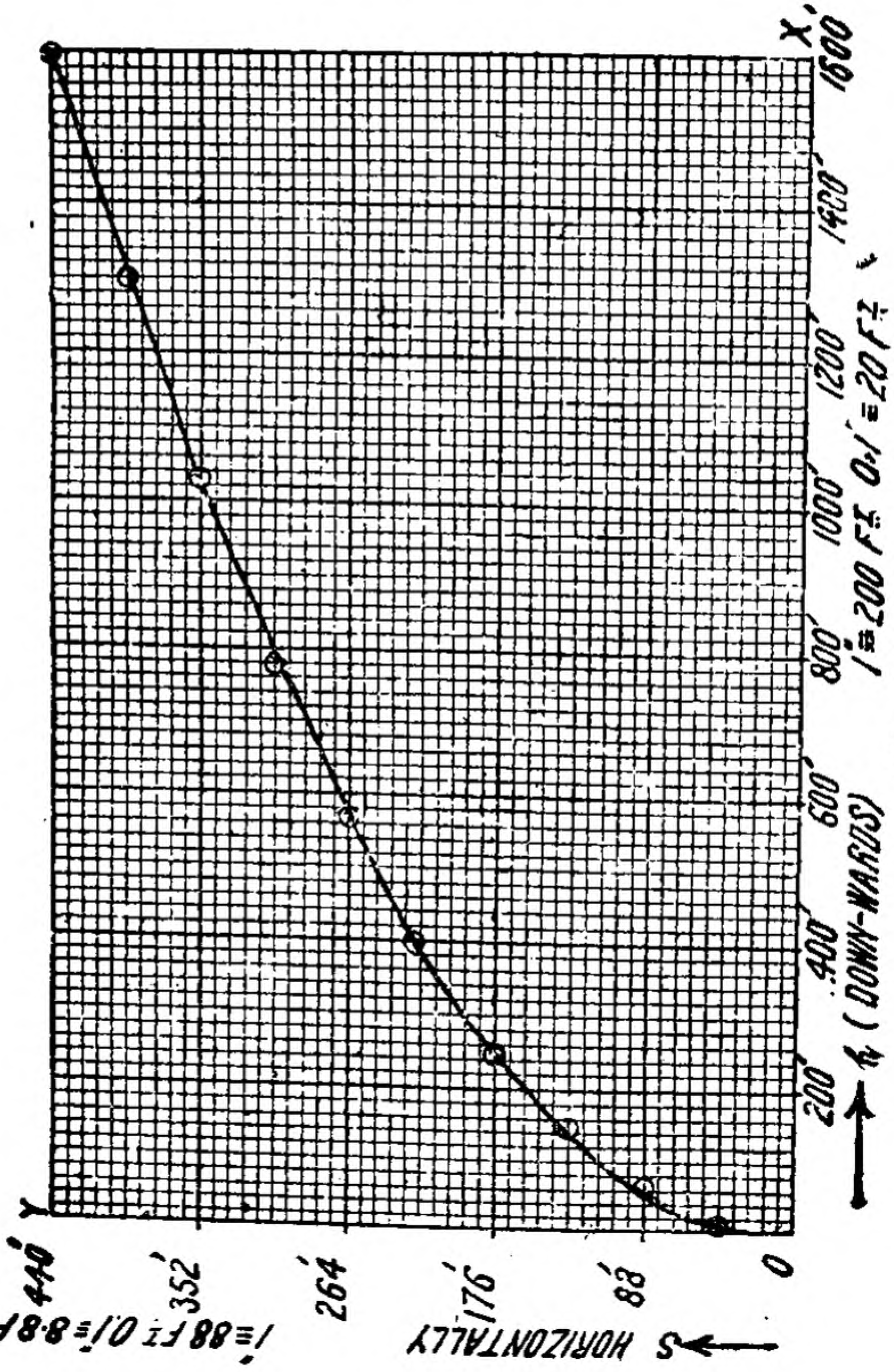
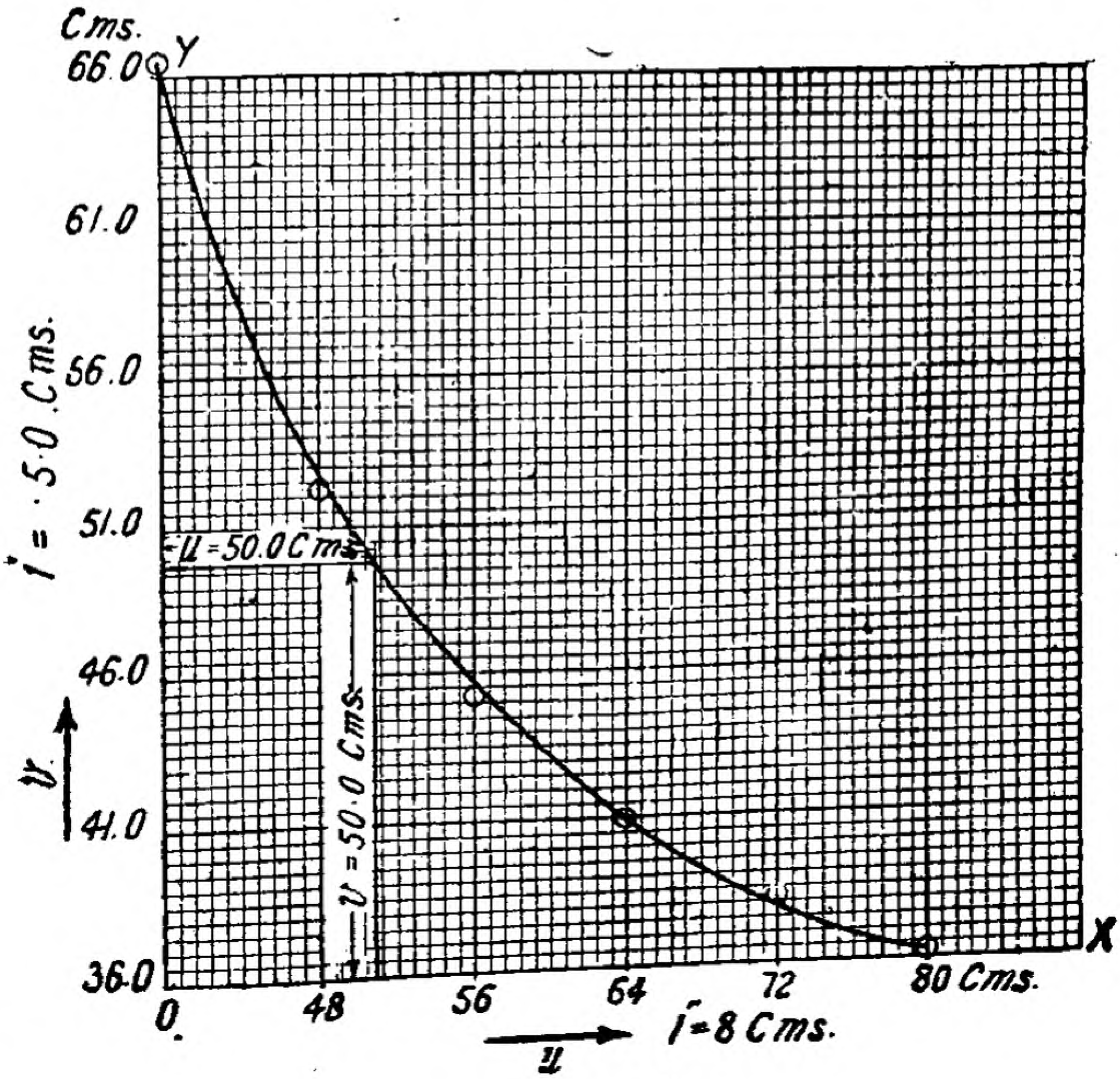


Fig. 4.

Example 5. Draw a graph for u and v in the case of a convex lens from the data given below and determine the value of f from it :

Obs. No.	1	2	3	4	5	6
u	40·0	48·0	56·0	64·0	72·0	80·6 cms.
v	66·6	52·2	45·2	41·0	38·3	36·4 cms.

For f, find a point on the graph for which $u=v$



50·0 cms. or $f=\frac{50\cdot0}{2}=25\cdot0$ cms. The curve is a 'Hyperbola.' Refer to figure 5.

Example 6. Plot $\frac{1}{u}$ against $\frac{1}{v}$, for a convex lens from the following readings and determine f for the lens.

Obs. No.	1	2	3	4	5	6
$\frac{1}{u}$	·025	·021	·018	·016	·014	·013
$\frac{1}{v}$	·015	·019	·024	·022	·026	·027

The origin for both $\frac{1}{u}$ and $\frac{1}{v}$ is at 0·10, the curve,

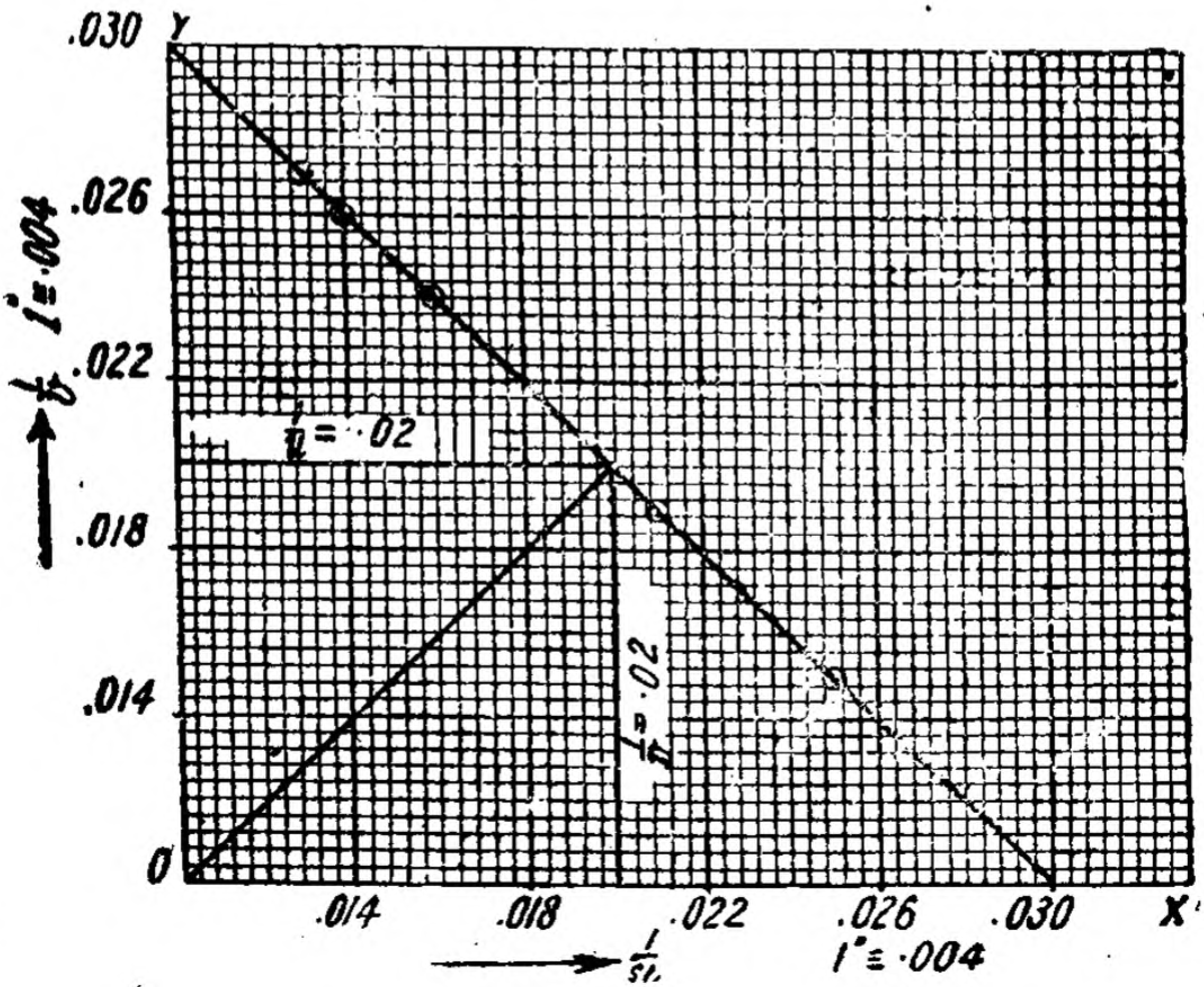


Fig. 6.

which in this case is a straight line, is symmetrical to the two axes. (Fig. 6). The co-ordinates of the point at which the perpendicular drawn from the origin to the graph cuts it, represent the value of

$$\frac{1}{u}=\frac{1}{v}=\frac{2}{f}=\frac{1}{\cdot 02} \text{ or } \frac{1}{f}=\frac{1}{\cdot 04}$$

$\therefore \quad f=\frac{100}{4}=25{\cdot}0$ cms. Or when $\frac{1}{u}=0$, $\frac{1}{v}=\frac{1}{f}$ or

$f=v$ or when $\frac{1}{v}=0$, $\frac{1}{u}=\frac{1}{f}$ $\therefore$ $f=u$. The origin being ·010,

$$u=v=f=\frac{1}{\cdot 04}=\frac{100}{4}=25{\cdot}0 \text{ cms.}$$

Example 7. Draw a graph for (*a*) natural numbers and their squares, (*b*) natural numbers and their reciprocals, (*c*) natural numbers and their logarithms.

The values for the squares and reciprocals may be obtained from the tables.

Example 8. Plot graphs for (*a*) angles and their sines, (*b*) their cosines, and (*c*) their tangents.

Note. Other graphs as exercises have been given with the various experiments.

Uses of Graphs :

The graphic method has proved to be very instructive and useful in understanding and solving many physical problems. The following are some of the uses to which it has been put :—

(1) It has proved very useful in determining the laws under which the variation of one quantity takes place with respect to another.

It has a special significance in higher research work both in the formulation of empirical laws and in predicting results of an experiment.

(2) We can study at a glance the changes undergone by one quantity with a change in another.

(3) We can test the accuracy of the results obtained in n experiment involving the change of two quantities.

(4) The mean value of the ratio of two variables is more accurately and easily determined.

(5) It has proved very useful in the calibrations and corrections of the readings of physical apparatus.

(6) By means of interpolation we are able to ascrertain the probable value of a quantity, which lies beyond the range of observation by experiment, or which is difficult to obtain under the circumstances in which the experiment is performed.

(7) It is easy to compare the behaviour of two substances when subjected to similar conditions in an experiment.

(8) It is instructive to study the anomalous behaviour of liquids in transition to the solid or vapour conditions, and in determining the temperature at which the change of state takes place.

(9) It is sometimes useful in solving physical problems and determination of areas enclosed by curves.

(10) It is of great practical importance in simplifying the study of the change of one quantity with respect to another in various problems of everyday life.

(11) It has proved to be of great utility in the record of several physical changes brought about in nature and many commercial processes.

CHAPTER III

MEASUREMENT OF LENGTHS AND ANGLES

Units of Length. The science of Physics is based largely on exact measurements and to render such measurements intelligible it is necessary to express them in some convenient or conventional standards. The unit of length adopted in the C. G. S. system (or in scientific world) is the **metre** or the distance at a particular temperature between the ends of a certain platinum rod deposited in the national archives at Severs. Wooden copies of this usually consist of a box-wood rule divided and subdivided into centimetres and millimetres.

In the F. P. S. system (which is adopted in the British Empire only) the standard of length is the **yard**. It is the length between two marks on a certain bronze bar (deposited with the Board of Trade) at a certain fixed temperature. The yard is divided and subdivided into feet and inches.

Methods of Measuring Lengths

(*a*) **Measurement of Straight Lines.** Suppose we want to measure the length of a straight line AB. In order to do this we should take a metre rod and place it edgewise on the line AB so that while A lies exactly on a cm. mark, say 1 cm. (not zero because the edge of the rod is always worn), B will lie either exactly under some division or between two divisions. In the latter case, the fraction of a millimetre necessary for exact measurement is etimated in tenths and the length AB (which may be supposed 10 cm. and 2·3 millimetres) is represented as 10·23 cm. If the length had been 10 cm. and 2 millimetres exactly it would have been put down as 10·20 cm. and not 10·2 cm. If AB happens to be exactly 10 cm., the length should be put down as 10·00 cm., the two zeros signifying that the measurement is supposed to be correct within tenths of a millimetre.

Error of Parallax. It is important to hold the scale so that the divisions are exactly in contact with the line to be

measured. This should be done in order to avoid errors due to parallax. Suppose we are to measure the length AB which when correctly measured is 5·90 cms. If the metre rod is

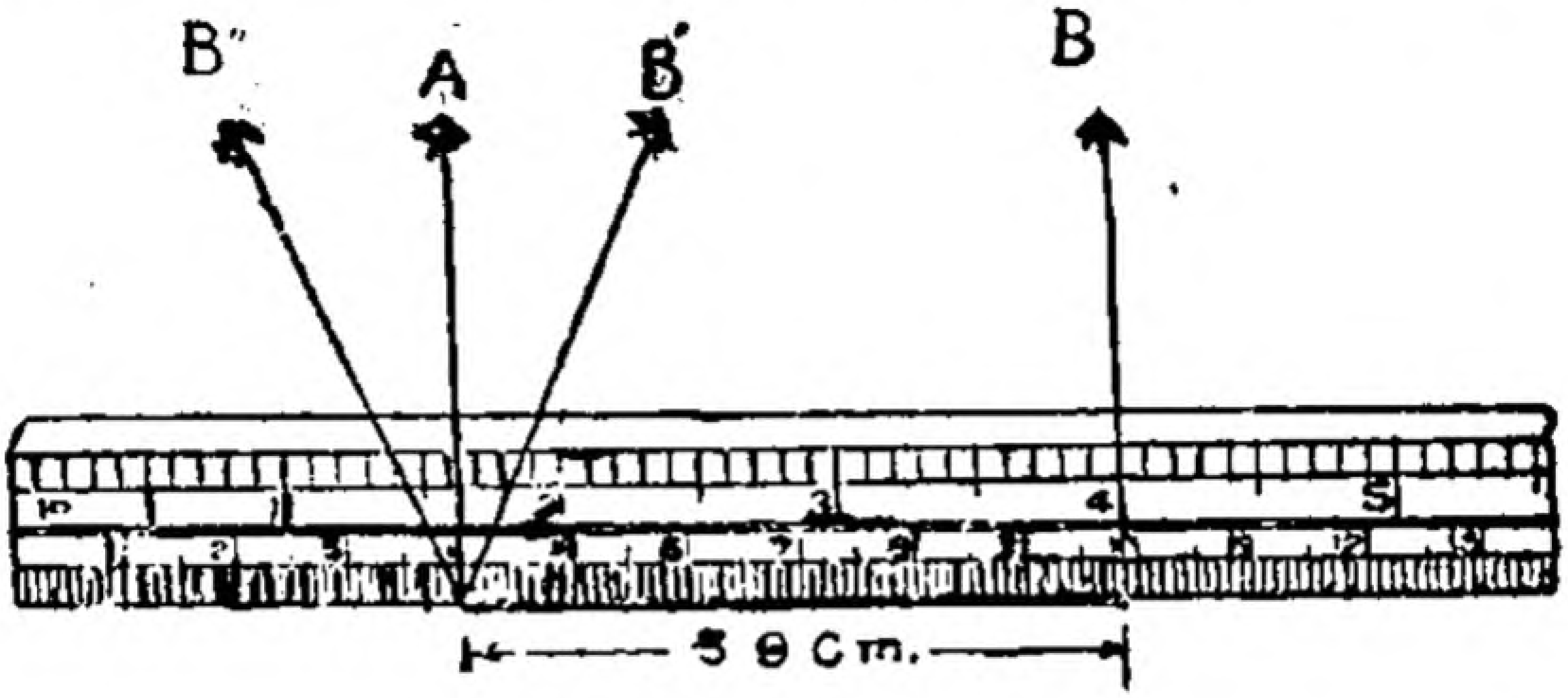


Fig. 7.

placed flat, the points A and B are not close to the division lines and the measurement will differ with the different positions of the eye of the observer (Fig. 7). B′ and B″ are incorrect positions of the eye. B′ makes the reading less than 5·93 cms., while B″ makes the reading more than 5·90 cms.

If the eye is not exactly above the points A and B, this error is always bound to occur.

Note—Do not use the zero of the metre rod, as the ends are often worn out.

Experiment 1. **To measure a straight line in centimetres and inches and to find the number of centimetres in an inch.**

Apparatus. ½ metre rod (mms. on one side and inches on the other).

Method. Draw three lines *a*, *b*, *c*, of lengths varying from 3 to 5 inches on a paper with a sharp pencil. Take a half metre rod and place it edgewise so that a well marked division, say 2 inches, comes over one end of one of the lines. Read the other end of the same line up to $\frac{1}{10}$th of an inch accurately. Next, place the cm. side of the metre rod edgewise on the line in the same manner and take readings as before. Take 3 observations for each line at 3 different places of the scale. Calculate separately for each line the value of an inch in cms. and then find the mean value. Record your observations in a tabular form as given below.

No. of observations	Length in inches.				Length in cms.				No. of cms. contained in an inch.
	Reading at one end.	Reading at the second end.	Length of the line in inches.	Mean length for *a*, *b*, *c* in inches.	Reading at one end.	Reading at the second end.	Length of the line in cm.	Mean length for *a*, *b*, *c* in cm.	
Line (*a*)									
1									
2									
3									
Line (*b*)									
1									
2									
3									
Line (*c*)									
1									
2									
3									

Precautions :—

1. Place the metre rod edgewise.
2. Do not use the zero of the metre rod as the ends are often worn out.
3. Avoid the error of parallax.
4. Take your reading up to $\frac{1}{10}$th of an inch accurately.
5. Record readings in a tabular form.

Question. If your results do not agree with the admitted result of 2·54 cm. in an inch, what can be the cause of the error ?

Measurement of curved lines.

Experiment. 2. **To measure the length of a curved line.**

Apparatus. A pair of dividers, metre rod, thread or a fine copper wire.

Method. Draw a curved line AB on your note-book and Measure its length in the following manner :—

(*a*) Give a knot to one end of the thread or cut the thread neatly with scissors and place the knot or the end of the thread at one end A of the line by pressing it with forefingers of your left hand and make a short length

coincide with the curved line and fix it with the right hand forefinger. Now place the left hand forefinger close to the right hand using your right hand against another short length along the curved line.

Fig. 8.

Proceed on like this till the end B is reached. The thread may be cut at this end either with a pair of scissors or a mark be made. Then measure the length of the thread between the knot at the end A and the mark at the end B. Take care that the thread does not slide on the paper between your fingers.

Note.—While placing the thread on the curved line be careful not to stretch it, otherwise the result is bound to be wrong because the length of the thread depends upon the force with which it is stretched. In order to do away with this error, use a thin copper wire.

(*b*) Take the dividers and open its length by about 2 mm. Place one leg of the dividers at A and turn the dividers, about this leg until the other leg is on the curved line. Now fix the latter and turn the dividers round until the first leg comes on the curved line and beyond the other leg. Go on repeating this operation till you reach the other end B of the curved line. Record the total number of steps covered by the dividers. Then take the same number of steps on the metre rod and note the distance traversed. If some part of the line has been left, measure it separately by placing the legs of the

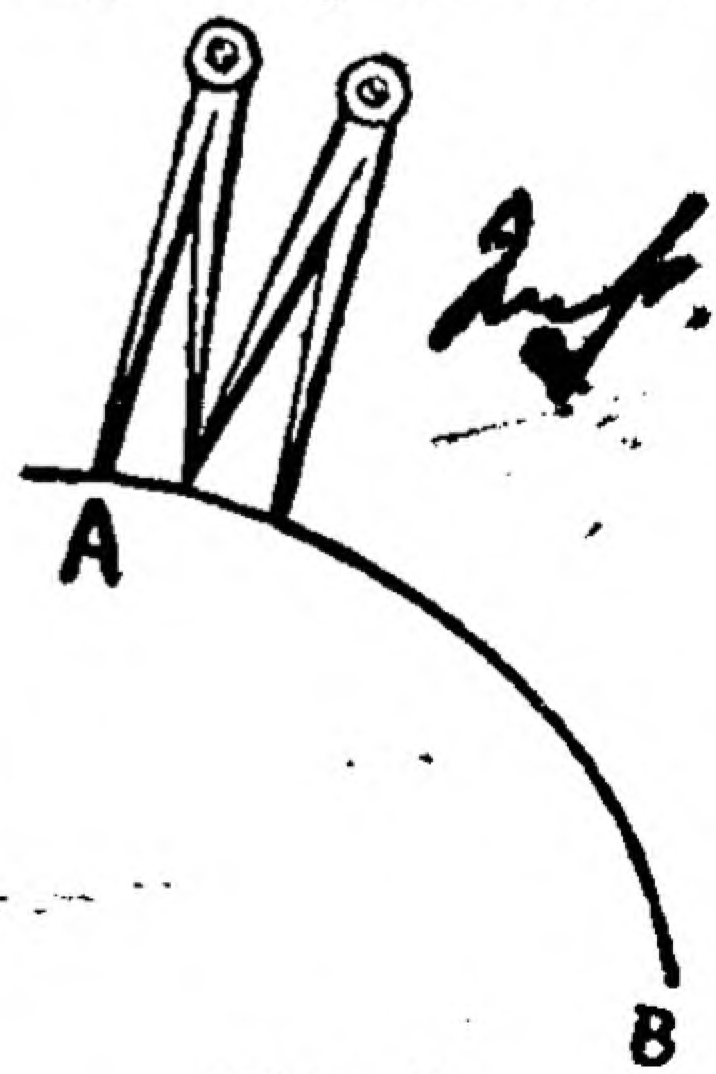


Fig. 9.

divider over that part and later on carry it to metre rod. *Be careful so as not to alter the distance between the legs of the dividers while repeating the process.* Repeat the process 3 times and take the mean.

Record thus :—

No. of observations	Dist. between the legs of the divider.	No. of steps taken	Dist. travelled on the scale.	Fraction left over.	Total length
1					
2					
3					

Mean :

Precautions :—

1. Take care not to slide the thread on the paper between your fingers.

2. Do not stretch the thread too much otherwise the result is bound to be wrong.

3. Do not alter the distance between the legs of the dividers while repeating the process.

Experiment 3. **To determine the diameter and circumference of (1) a disc or a coin ; (2) a cylinder, and to deduce the value of π.**

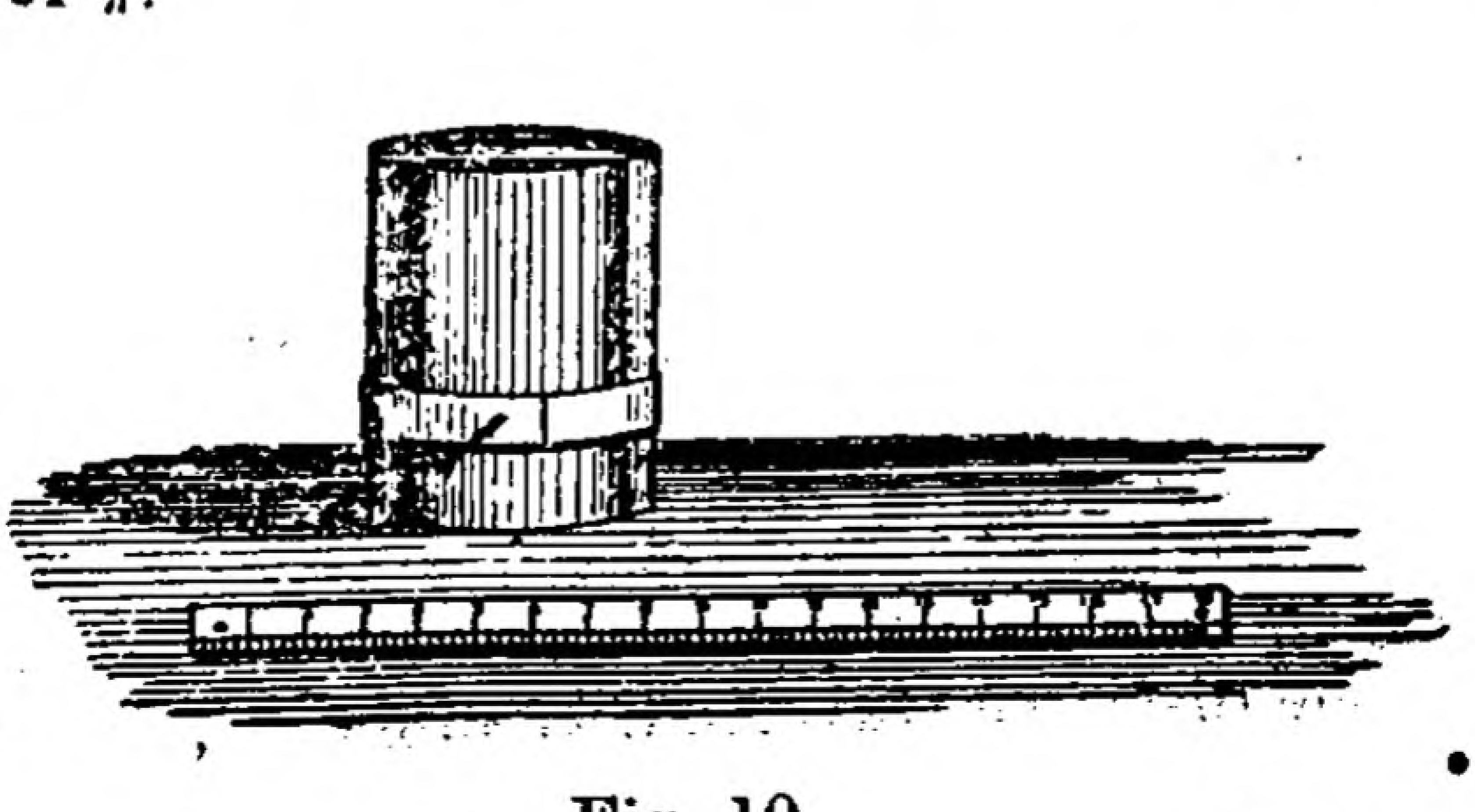


Fig. 10.

Apparatus. A wooden disc (of 5 cm. diameter and 1 cm. thick), a pice, a metallic cylinder, straight slips of thin paper thread, metre rod etc.

Method. (*a*) Wrap a paper slip tightly round the edge of the disc, coin or cylinder and allow the ends to overlap (Fig. 10). Take a pin and prick the overlapping portion. Unwrap the slip and lay it flat on the table. The two pin points may be well marked with circles or crosses. Measure the distance between the two pin pricks by placing a metre rod edgewise over it. This would give us the circumference. Repeat the operation three times using different slips.

For measurement of the diameter, place the metre rod edgewise across the circular face and keep a certain fixed mark, say 5 cm., exactly on the circumference. Move the rod so that it passes through the centre of the disc or move it so as to obtain the highest reading on the circumference on the opposite side. The difference between the two readings gives the diameter. Repeat similar observations from other places.

(*b*) Make a fine mark on the edge of the disc or coin. Next place the disc or the coin edgewise on the metre rod so as to have the mark on a centimetre division. Roll the coin in a line with the edge of the scale and read the position of mark after one complete revolution. Do it three times, starting every time from a new mark of the scale. *Take care that the coin does not slip but rolls on the scale in a line with the graduated edge.*

(*c*) Take a fine thread and wind it round several times (say ten times) a cylinder keeping the windings tight and close to one another. Mark the windings of the thread with a pencil along an axial line (line parallel to the axis.) Unwind the thread and measure the distance between the two marks on the 0th and 10th turn. The circumference will be equal to this distance divided by ten turns. Repeat it three times using turns from 10 to 15.

Tabulate the results thus :

No. of observations.	Circumference	Diameter.	$\pi = \frac{\text{Circumference}}{\text{Diameter}}$.
1			
2			
3			

Mean :

It will be seen that the ratio in the last column would be a constant quantity.

Precautions :—

1. Wrap the paper tightly. Measure the distance between the two pin pricks by placing a metre rod edgewise over it.

2. Roll the coin in a line with the edge of the scale and read the position of the mark after one complete revolution.

3. Take care that the coin does not slip but rolls on the scale in line with the graduated end.

4. Mark the windings of the thread with a pencil along an axial line (parallel to the axis).

Sources of error:— (1) The edge of the cylider may not be quite flat.

(2) The edges of the coin may not be uniform.

Beam Compass. It consists of two finely pointed legs which can be fixed at any point we like. These two legs can be made

Fig. 11.

to move over a straight bar (usually of wood). Suppose we are to measure the length of a straight line AB. The two legs are adjusted by sliding so that one leg comes on the point A and the other comes on the point B. The legs are fixed by means of the attached screws. If the beam compass is graduated then the distance can be read directly, but if not graduated the distance between the points can be read by placing the two legs on a metre scale as is done in the case of dividers. In fact a beam compass is simply a

The Vernier

This is a device for readily estimating the fractions of the smaller parts of a measuring scale ; its use avoids the necessity for minute sub-division. The method was devised by Paul Vernier in 1630. It consists in the addition of an auxiliary scale that slides along the principal one and is graduated so that a number (n) of its divisions is equal to one less ($n-1$) or one more * ($n+1$) than those of the principal scale. Verniers are employed in many physical instruments.

To Construct a Scale and a Vernier.

Cut out two strips of cardbodrd AB and CD (Fig. 12). On AB mark divisions 0, 1, 2, etc., exactly 1 cm. apart upto about 15 cm. Cut off CD exactly 9 cm. long and by a scale or millimetre paper divide it accurately into 10 equal parts each 9 mm. long. Number the division marks 0, 1........ to 10.

Place the two strips side by side as shown in the figure. AB is called the scale. and CD the vernier. Place the two zeros in a line.

Since 10 divisions of the vernier are equal to 9 divisions of the scale therefore 1 division of the vernier $=\frac{9}{10}$ division of the principal scale. Therefore the difference in length between a scale division and a vernier division $=\frac{1}{10}$th (or $\cdot 1$) of a scale division. This difference is called *vernier constant* or *least count* of the vernier.

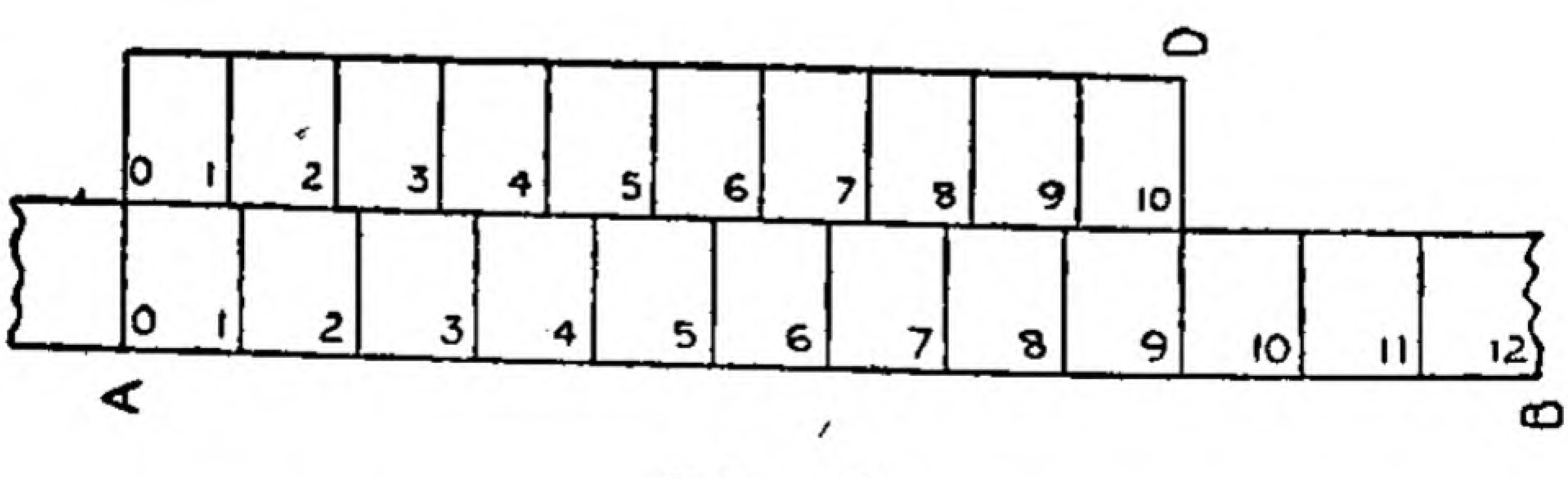


Fig. 12.

Method of examining a Vernier. The principal of all verniers is the same but before taking a reading with the vernier, note the following :

*This type of Vernier reads backwards and is not much used in practice.

(1) The value in fractions of an inch or centimetre of the smallest part of the principal scale.

(2) The number of parts into which the vernier is divided.

(3) The relationship between the divisions of the vernier and of the principal scale.

To study this, bring the zero of the vernier into coincidence with a scale division, the relationship then can be easily observed.

The *least count* of the vernier is the difference between a scale division and a vernier division. This difference is also known as *vernier constant.*

To calculate it, suppose

n divisions of vernier $=(n-1)$ scale divisions.

one division ,, ,, $=\frac{n-1}{n}$ of a scale division.

The difference between a vernier and a scale division (the least count) or the vernier constant

$$=1-\frac{n-1}{n}=\frac{1}{n}.$$

Having found the vernier constant (least count) place one end of the body opposite to the zero of the principal scale and read the smaller of the two scale divisions between which the other end of the body lies. Bring the zero of the vernier against this other end and notice which vernier line (mth) coincides with a scale line. The reading is given by adding to the scale division already noted the product of the vernier constant (least count) and the number of vernier division (m) coinciding with a scale line, *i.e.*

Total length $=$ scale reading $+\frac{m}{n}$, where m is the number of the vernier line coinciding with a scale line and $\frac{1}{n}$ is the vernier constant.

The Model Vernier (Fig. 13). It consists of two long strips of wood, one having an inch scale and the other having a centimetre scale engraved on it. Both the scales are divided into ten equal parts and are fixed on the same

wooden base leaving a space (or rectangular groove) in which can move a third small strip of wood on which there are 10 graduations equal to nine of the small scale divisions (both in inches and centimetres). The difference between a

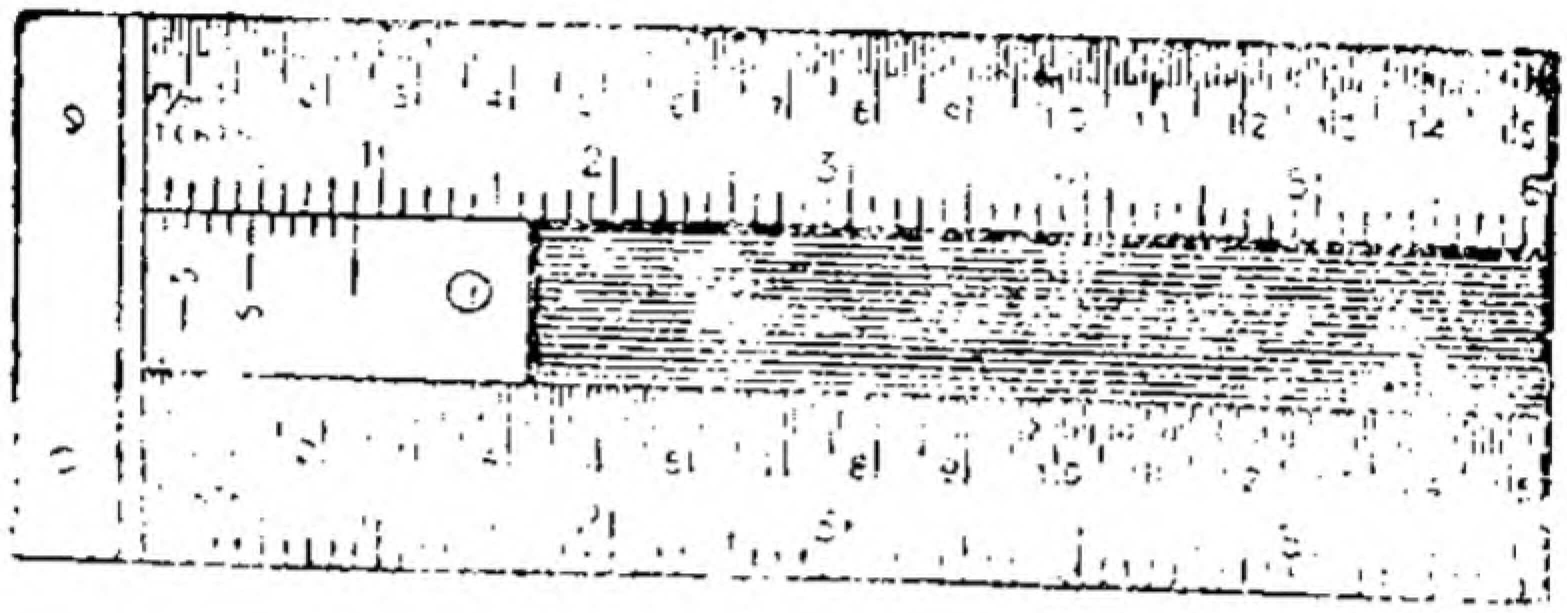


Fig. 13.

small scale division and a vernier division is ·1 of a small scale division or ·01 of a big scale division. In order to measure the length of a cylinder or wooden rod, we place it in the groove such that one end of the body is against the zero of the scale (Fig. 14). Move the vernier till it touches the other end. In order to read the length of the body proceed as follows :—

Method of Using a Vernier. Suppose that the length of a body XY is to be measured by means of the principal scale and vernier in inches. Place the body so that the end X rests against the fixed wooden strip and hence coincides

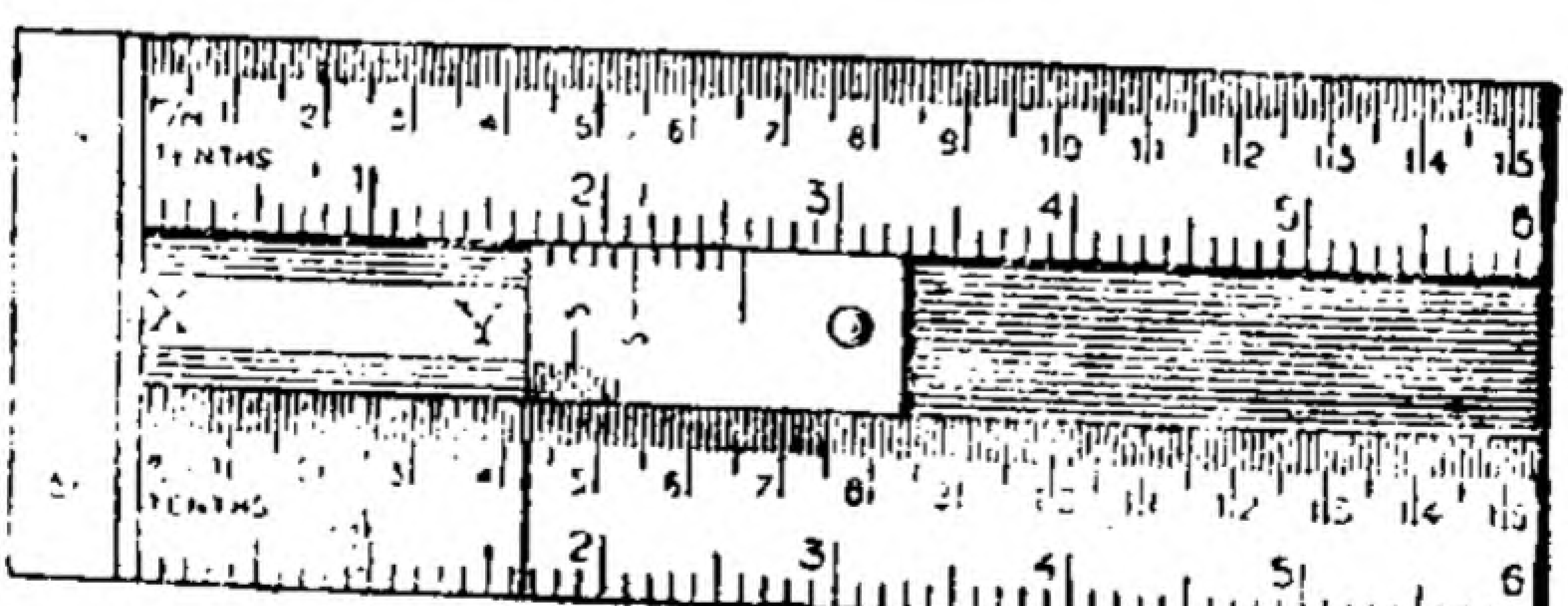


Fig. 14.

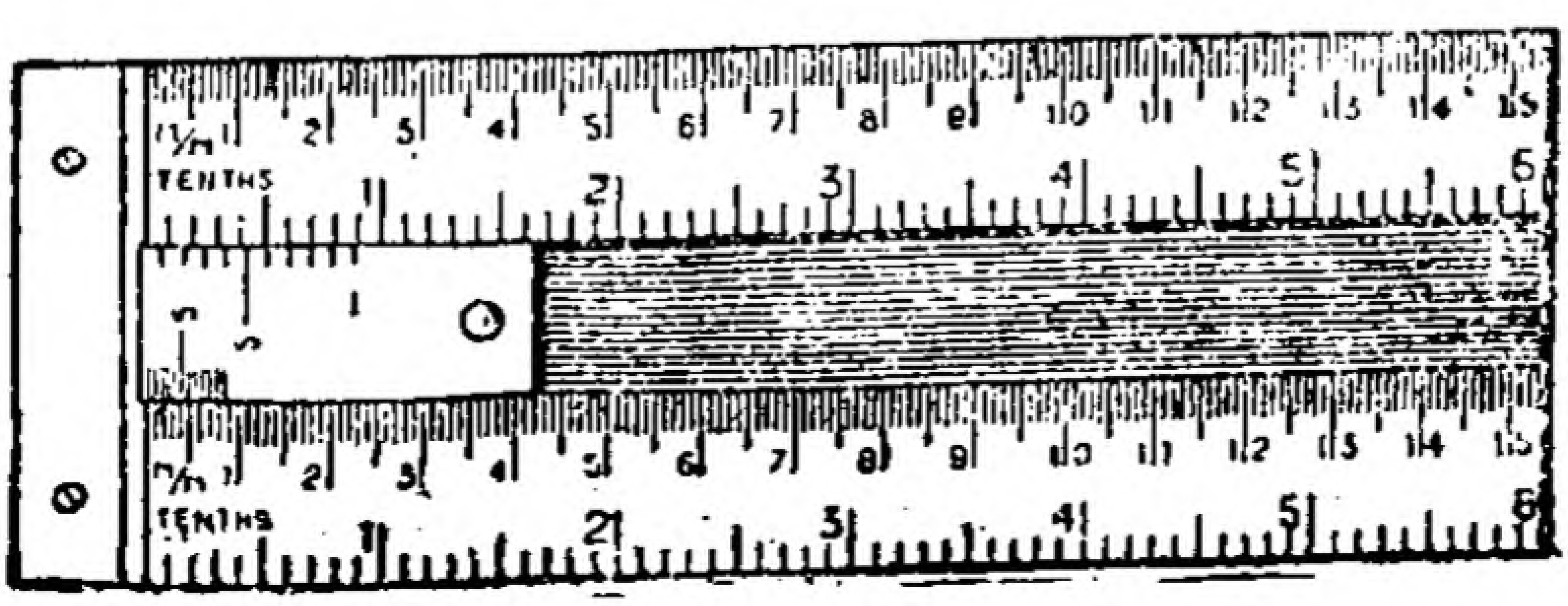
with the zero division of the principal scale as shown in Fig. 14. Then in the case illustrated the end Y comes between 1·6 inches and 1·7 inches of the principal scale. To determine the fraction of the scale division with the help of the vernier, place the zero mark of the vernier against the end

Y of the body. Looking along the two scales it will be seen that in general their divisions do not coincide, but that one division of the vernier scale (in this case division 8) is in a line with a division of the principal scale. This indicates that the length of the body XY is 1·68 inches (scale divisions as will be clearly seen from the following considerations :—

The end Y is in advance of the scale division 1·6 inches and lies between the divisions 1·6 and 1·7 inches. We are to estimate the distance between the end Y (which is coincident with 0 division of the vernier) and the division 1·6. The division 2·4 inches of the scale is coinciding with the 8th division of the vernier scale. Distance between the scale division 2·3 inches and vernier division 7=·1 small scale division. Distance between the scale division 2·2 inches and vernier division 6=·2 small scale division. Distance between the scale division 2·1 inches and vernier division 5=·3 small scale division. Distance between the scale division 2·0 and vernier division 4=·4 small scale division. Distance between the scale division 1·9 and vernier division 3=·5 small scale division. Distanee between the scale division 1·8 and vernier division 2=·6 small scale division. Distance between the scale division 1·7 and vernier division 1=·7 small scale division. Distance between the scale division 1·6 and vernier division 0=·8 small scale division.

Thus XY is ·8 small scale division greater than 1·6 inches, *i. e.*, the length is 1·68 inches.

The Zero Reading or Zero Error. Before using any vernier it is necessary to see if the zero line of the vernier coincides with the zero line of the scale. If not, we are to see whether the zero line of the vernier is towards the right or left of the zero line of the scale. If the zero line of the vernier happens to lie before the zero line of the scale, it means the vernier scale has been displaced a little from its proper position and the *reading of the object ought to be more.* (See Fig. 15).



In this case zero of the vernier is towards the left of the zero line of the scale. The figure shows that the 8th vernier line coincides with a scale line (inches side). The fraction between the small graduations 1 (imaginary) of the scale and 0 of the vernier is ·08 inch. Therefore the zero reading or the distance between 0 of the scale and zero of the vernier is ·02 inch. This reading is negative and is put down as —·02 inch.

If the zero line of the vernier is displaced towards the right (Fig. 16), *i. e.*, after the zero line of the scale, it means *that the reading is a little more than the actual reading.* The figure shows that the zero of the vernier is after the zero line of the scale and 5th division of the vernier is in line with a scale division (inches side). Evidently the reading of the zero of the vernier is $5 \times \cdot 01 = \cdot 05$ inch, *i. e.*, the zero of the vernier is away from the zero of the scale (from its real position) by ·05 inch because in a well made instrument they should be in contact. Hence the error in this case is +·05 inch.

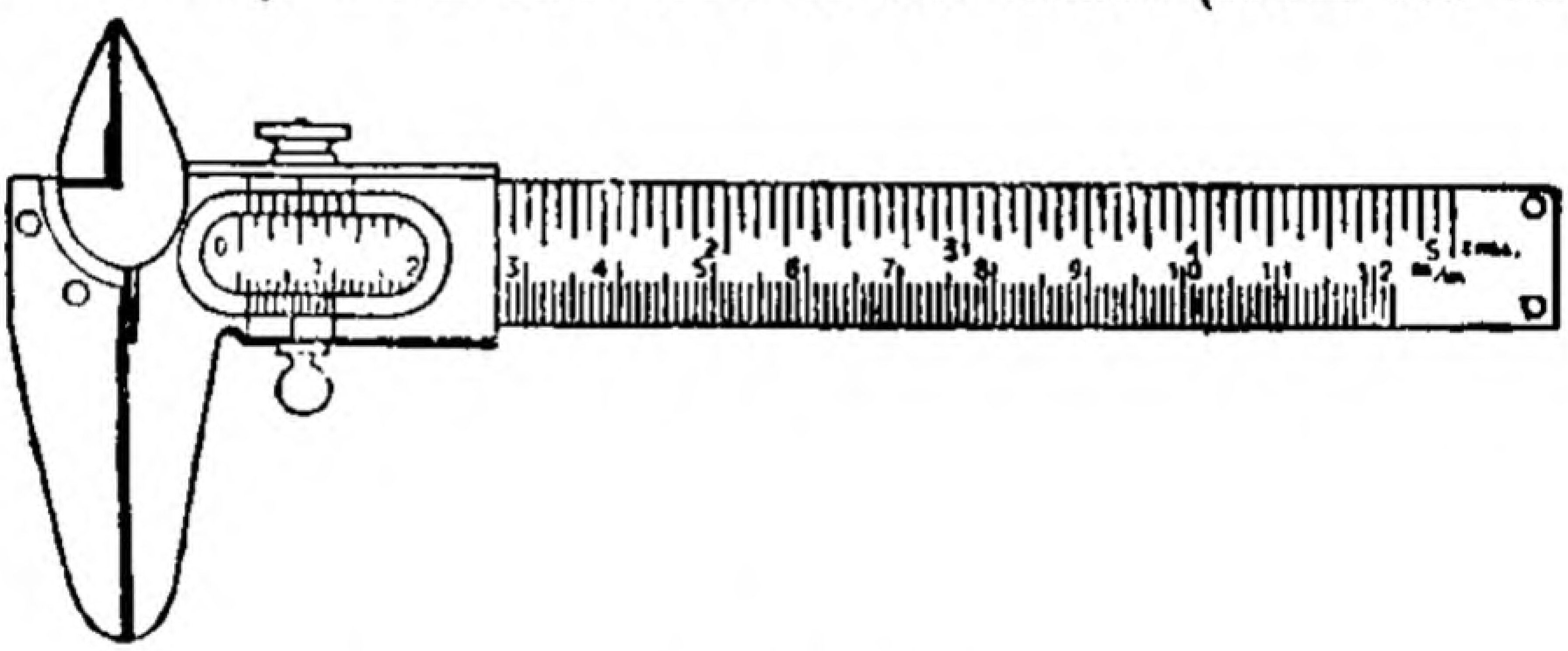


Fig. 16.

To Correct the Reading for Zero Error. Change the sign of this zero error and this would give you zero correction. Add this correction algebraically to the true reading.

In the first case :

Zero error = —·02 inch. Zero correction = +·02 inch.

Hence true length

$= x + \cdot 02$ inches $= x + \cdot 02$ inches,

where x is the uncorrected length in inches.

In the second case

Zero error = +·05 inch

Zero correction = —·05 inch.

Hence the true length $= x + - .05$ inches $= x - \cdot 05$ inches.

Barometer Verniers.—The type of barometer ordinarily employed in the laboratory has two scales, one graduated in millimetres and the other in inches and fractions of an inch. Verniers are provided on both scales. They are illustrated in Figs. 17*a* and 17*b*. In the metric-vernier we find that the number of vernier divisions is double the number of scale divisions. This is done to remove the inconvenience of having small division on the vernier. Here 10 divisions of the vernier are equal to 19 small scale divisions. To calculate the vernier constant we apply the original principle.

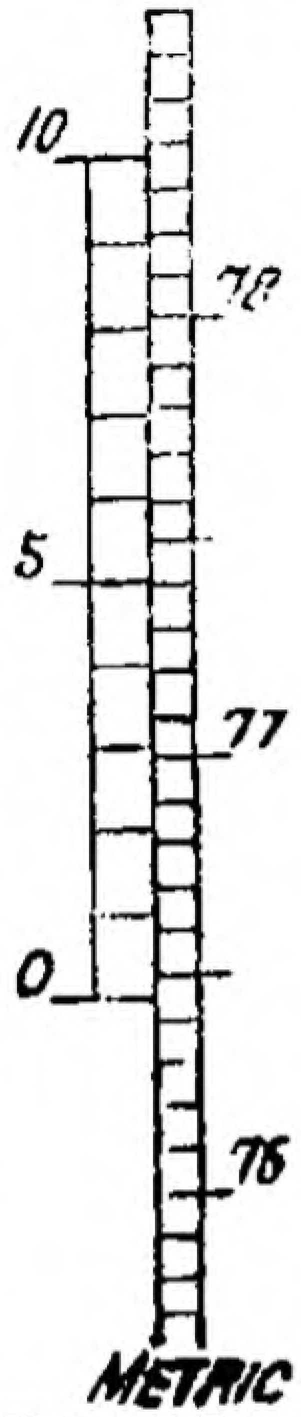


Fig. 17(*a*)

10 divisions of vernier are equal to 19 divisions of the scale.

1 division of vernier is equal to 1·9 of the scale.

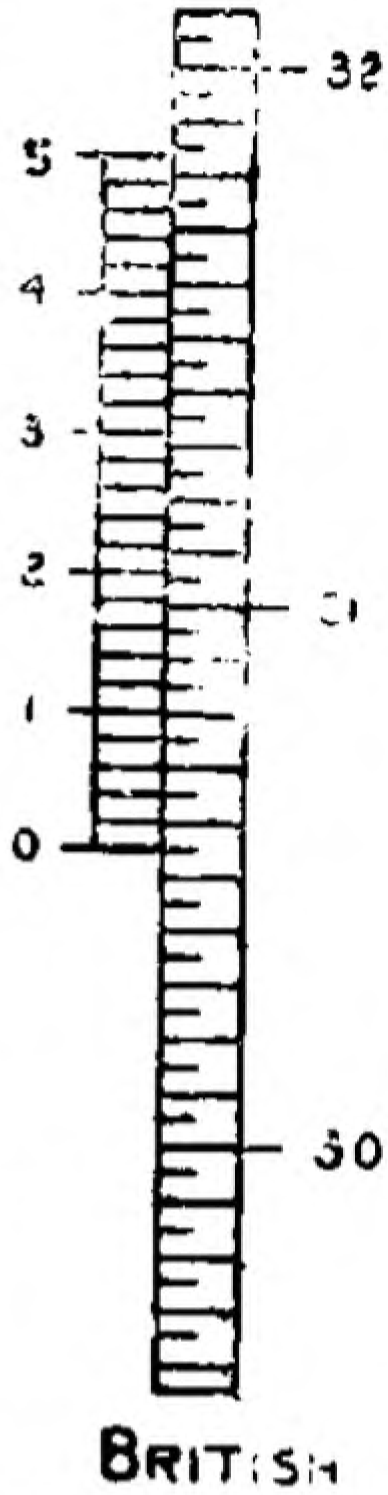
Difference between 1 vernier division and 2 scale divisions = ·1 scale division. Therefore vernier constant = ·1 mm.

In this case we must see by how much a given vernier division falls short of a scale division. For instance, if 10 vernier divisions had equalled 29 of the scale, the vernier constant would still be ·1, because all that is necessary is that a vernier division should be a little less than a scale division. The only advantage is that the vernier division being of larger size can easily be read.

In the British vernier (*i. e.*, on the inches side) the principal scale is divided into twentieths of an inch, 25 divisions of the vernier scale are equivalent to 24 divisions of the principal scale. The vernier constant (or least count) is therefore $\frac{1}{25}$ of $\frac{1}{20}=\frac{1}{500}$ inch.

In taking readings the reading in inches and twentieths of an inch is obtained from the principal scale ; ·002 is added to this reading if coincidence takes place at the first vernier division, ·004 in. if coincidence is at the second division, and so on.

In the figure the reading by the principal scale is 30·5 in. The 24th mark on the vernier coincides with a scale division, therefore, reading by vernier $= \cdot 002 \times 24 = \cdot 048$ in. Therefore total reading $= 30 \cdot 5 + \cdot 048$ in. $= 30 \cdot 548$ inches.



The Sliding Calipers.—It consists of a steel bar with a scale engraved on it. The rod has two jaws projecting at rt. angles to it. One jaw is fixed and the other is capable of moving backwards and forwards. The movable jaw which can be fixed by means of a screw has a scale marked on it called the vernier scale. When the faces of the jaw are in contact, the zero line of the vernier scale should coincide with the zero line of the fixed scale. The dimensions of an object are measured by noting how far a zero division of the vernier scale has moved along the fixed scale when the jaws have been separated until the object is just touched by the faces of the jaws. Before taking a measurement it is necessary to note whether the fixed scale is divided into millimetres or into parts of an inch and to what fraction of a scale division the vernier is intended to read.

Fig. 17 (*b*)

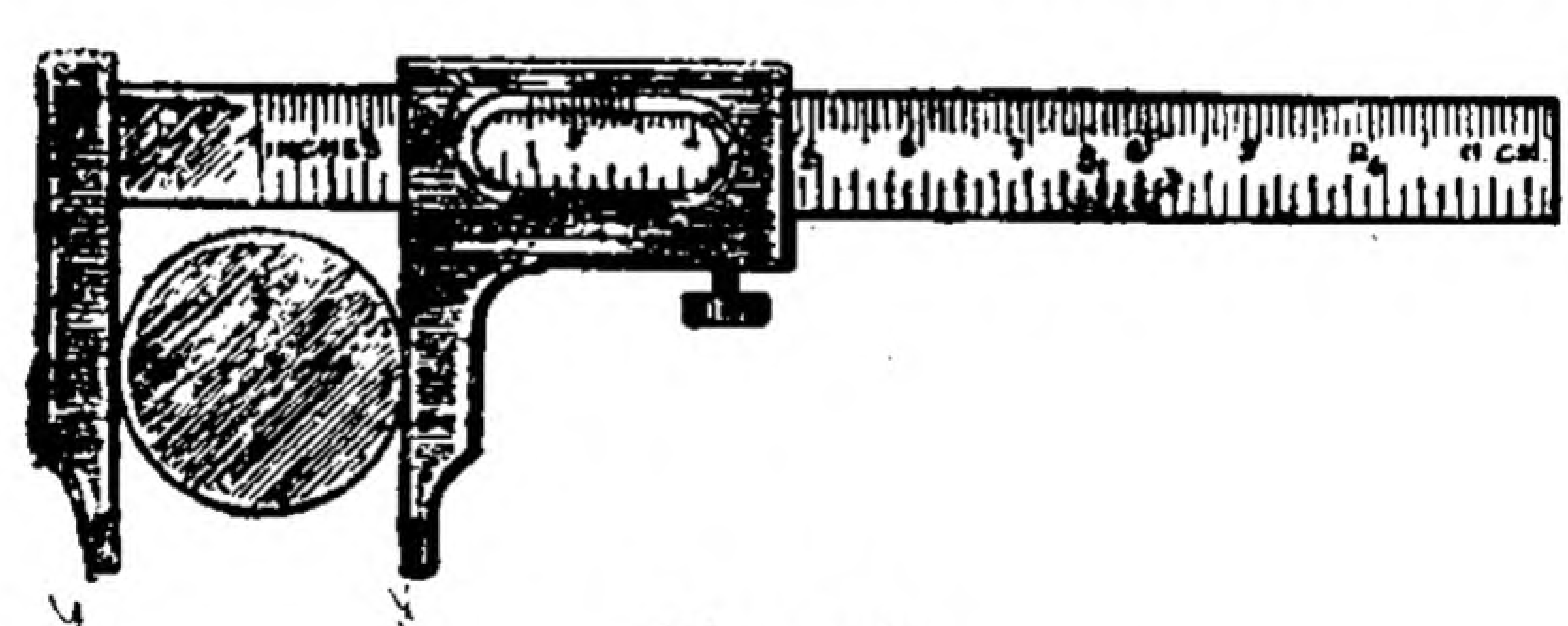


Fig. 18.

Experiment 4. (*a*) **To find the length of a knitting needle (with rounded ends),** (*b*) **to measure the diameter of (1) a sphere and (2) a cylinder.**

Apparatus.—A cylinder, a sphere, a knitting needle (with rounded ends), vernier calipers and Model Vernier.

Method. (*a*) Place the knitting needle in the rectangular grove (XY in Fig. 14) so that the end X rests against the fixed wooden strip. Move the small strip of wood upon which vernier is marked till it comes in contact

with the end Y. Then read the principal scale before the vernier begins. Next find out which division of the vernier coincides with any division of the principal scale. Then the total length of the knitting needle=reading of the principal scale+division of the vernier which coincides with any division of the principal scale × vernier constant. The true length would be given after correcting for the zero correction. Record observations as given after part (*b*).

(*b*) Separate the two jaws of a sliding calipers and place the sphere and cylinder turn by turn touching the fixed jaw and slide the movable jaw till it just touches the cylinder or the sphere. Do not press very hard but let it just touch. Fix the movable jaw at this position. Note the position of the zero of the vernier. Repeat your observations four or five times measuring the sphere or the cylinder along different diameters.

Record observations both for part (*a*) and (*b*) thus :—

Vernier Constant* =

Zero Error.........(1) (2) (3) (4).

Mean Zero Error =

Zero Correction =

No. of observation.	Reading of the length or diameter before the vernier scale.	Reading of the vernier division which coincides with scale division.	Observed length or diameter	Corrected length or diameter	Mean length or diameter

Precautions.—1. Do not press the jaws (in case of vernier calipers), and movable wooden strip (in case of model vernier) very hard but let them just touch the object.

2. Take the zero error (if any) into account.

Sources of error. (1) The jaw attached to the vernier may not be at right angles to the principal scale.

(2) It is possible that none of the vernier division may be coinciding exactly with some division of the main scale.

*Its calculation must be recorded here.

Questions.

(1) What is a vernier and why is it so called ?

(2) What is vernier constant ?

(3) What is the method of calculating vernier constant ?

Exercise 1. Find the diameter of a rupee by vernier Calipers.

Exercise 2. Construct a model vernier.

The Screw-Gauge (Fig. 19*a*, 19*b*)—The screw-gauge furnishes a very accurate means for measuring the dimensions of small objects. It consists of a U-shaped fixed frame AFB. The screw D works in a cylindr cal nut SS_2 called the stem of the frame AFB. On the stem is engraved a line

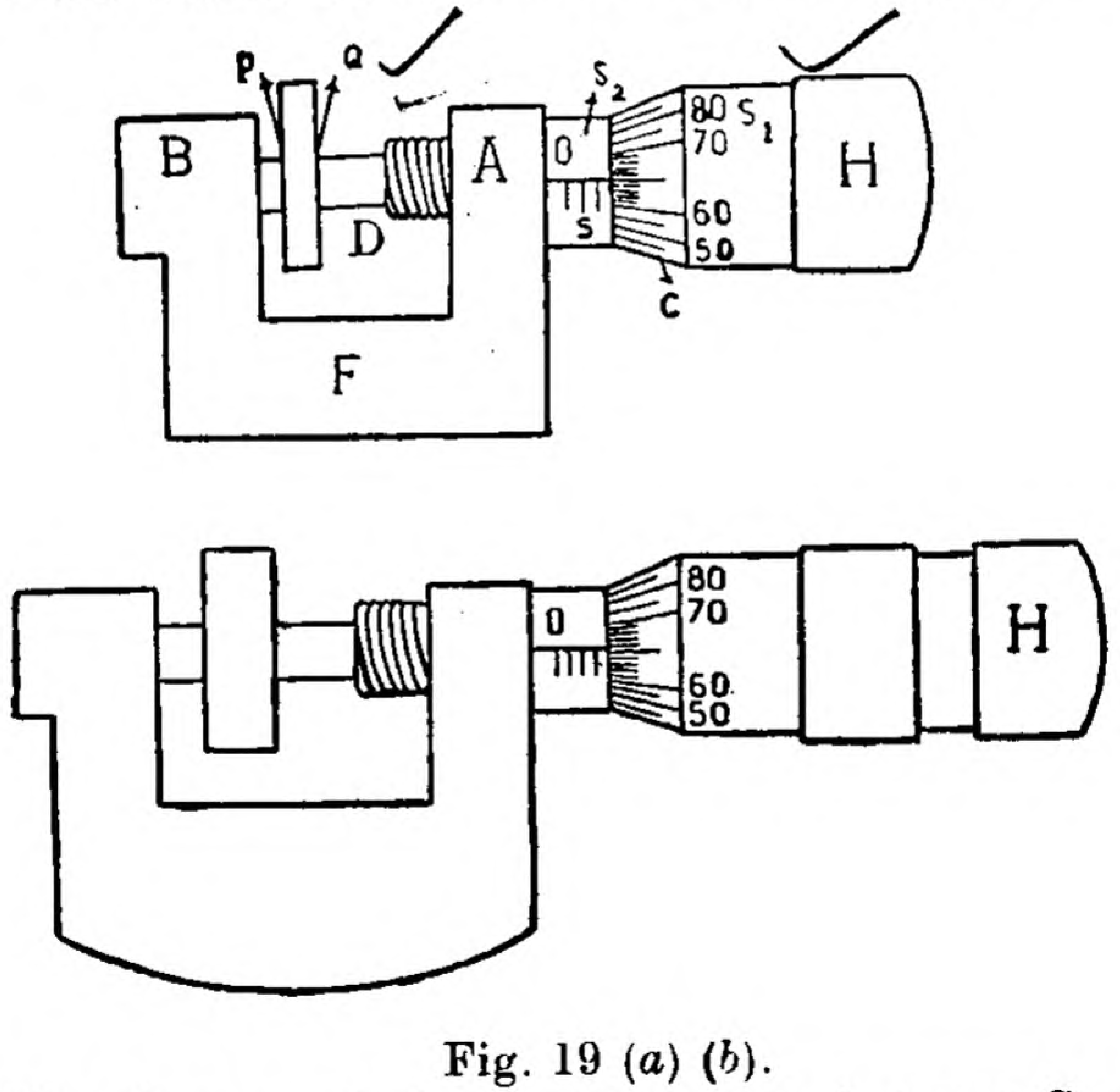


Fig. 19 (*a*) (*b*).

parallel to the axis of the screw shown between S_2 and S. The stem is divided in millimetres. The screw is fixed on the right hand side to the screw head S_1H. The end C of the screw head is bevelled and is divided into 50 or 100 parts. The end of the screw D is a truly planed surface Q, and a similar surface P is obtained on the other end of a steel

plug fixed inside the frame AFB. For adjustment, see that the zero line of the scale on C coincides with the axial line of the scale on SS_2. At that time the two plane faces P and Q will be in contact. The distance through which the screw D moves in one complete revolution is called the pitch of the instrument. The cap or milled head H (in some forms of the instruments) is not rigidly fixed to the end of the screw, but slips on with a little friction [Fig. 19 (*b*).] If the gap is closed, then on turning the head, the screw will travel forward and will press lightly along the fixed end, but when the milled head is not rigidly fixed, it will slip on the screw stem.

Experiment 5. **To measure (*a*) the diameter of a wire, (*b*) thickness of a cover glass slip using a screw gauge.**

Apparatus.—A thin copper wire, cover glass slip, screw gauge.

Method. Before taking a measurement by a screw gauge, find (1) the pitch of the screw gauge, *i.e.*, the distance through which Q advances or recedes by one complete rotation of the screw head S_1H. This is obtained by observing whether one division or half a division of the scale SS_2 is uncovered when the screw head S_1H is rotated backwards by one complete revolution ; (2) the least count or the scale value of one division of the scale on C. If the pitch of the screw D is 1 mm. and C is divided into 100 equal parts, 1 division of C represents $\frac{1}{100}=\cdot01$ mm. This is known as the *least count* of the instrument.

Zero Error. If the instrument is perfect, the zero line of the circular scale on C (when the gap is just closed) coincides with the axial line on SS_2. If this is not so, the zero reading (in divisions) with the proper sign ought be taken. The wire or the glass slip is placed between the faces P and Q and the milled head H is rotated until it is lightly gripped between the faces. Avoid undue pressure. Read the pitch scale in millimetres and the circular scale in divisions. Take from 10 to 15 readings. The mean of these readings corrected for zero gives the corrected diameter.

NOTE.—It is always better to take all screw-gauge readings in mm. and convert them to centimetres when proceeding to calculate or when writing down the final result.

Record thus :—
Pitch of the screw =
No. of divisions on the cap C=
Least count of the instrument=

The smallest length which a screw gauge can read is called the least count of the instrument.

Before using a screw gauge first find the pitch of the screw and the least count and then see if there is any zero error in the instrument.

Zero Error =(1) (2) (3) (4) (5)
Mean „ =
Zero correction =

No. of observation.	The reading on the straigt scale (complete revolution.)	The reading on bevelled surface C (fraction of a revolution).	Diameter of the wire or thickness of the glass slip.	Corrected diameter.	Mean diameter.

$\frac{1}{5}$ 100 1000 20 $\frac{1}{200}$ .005 1000

Precautions

1. Do not press the head of the screw very hard but let the two faces P and Q just touch.
2. Take the zero error into consideration.

Questions. (1) Define 'pitch' and 'least count'.
(2) What is meant by back lash error and how is it eliminated ?

Exercise. Find out the thickness of a tin plate using a screw-gauge.

NOTE. It should be noted that definite numbers are allotted to wires of different diameters. If the diameter

of a wire is 1·22 mm., its number according to **Standard wire Gauge** (S.W.G.) is 18.

In order to verify the correctness of the diameter of a wire, consult the S.W.G. table.

Spherometer

A spherometer resembles closely in principle a screw-gauge. It consists of a tripod A, the legs of which are of

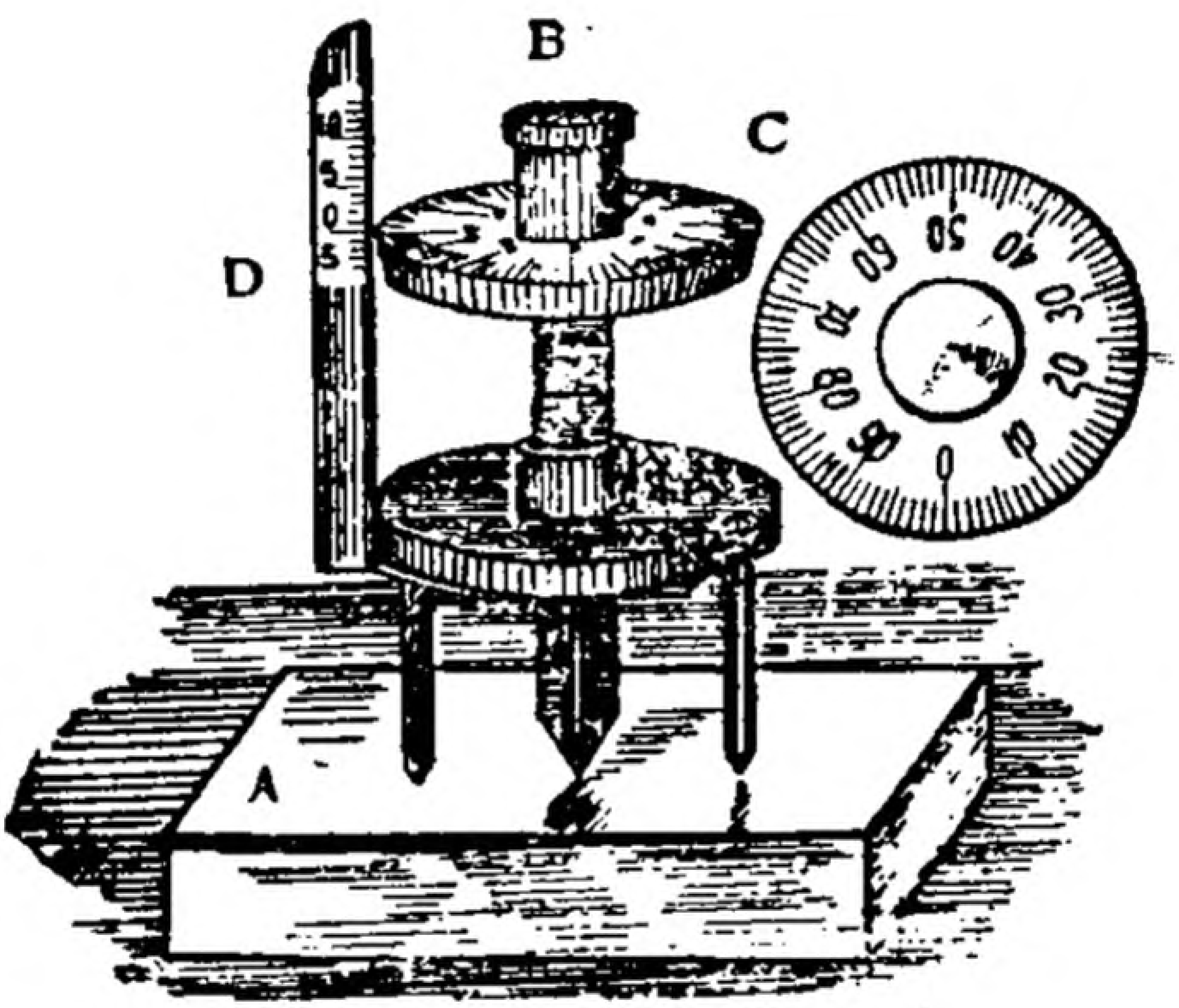


Fig. 20.

equal length and are adjusted relatively to each other so that the three points occupy the corners of an equilateral triangle. A fine screw which works through the centre of the tripod, terminates above in a milled head B. A large circular disc C has its edge divided into a fixed number of equal parts (usually 100). A vertical scale D divided into millimetres is fixed to one arm of the tripod and has its divisions close to the edge of the disc. This is called the *pitch scale*. The edge of the disc presses close to the vertical scale. While taking a reading see which division on the disc is opposite to the vertical scale.

Method of examining a spherometer. Place the spherometer on a glass plate (or a glass slab) so that the three legs and the screw point simultaneously touch the plane surface. In this position in a well-designed instrument the zero of

the circular scale should be exactly opposite to the zero line on the vertical scale. In practice, however, this is rarely the case. It is, therefore, necessary to determine the zero error or zero reading of the instrument. To do this, rest the spherometer on a plane surface such as a glass slab. Turn the head of the screw until its end (point of central leg) just touches the surface of the glass slab. When this is the case a gentle knock against one of the legs of the instrument with a loosely held pencil will make it spin round a little way or on touching the frame lightly with the finger it can be felt to rock. Find the division of the head scale at which the instrument just begins to rock or spin, and the division at which it just sticks. The mean of these may be taken as the reading for which the end of the screw comes into contact with the surface. If in the above adjustment the 0 mark of the head scale is against the 0 of the pitch scale, the instrument has no zero error. If this is not the case, the number of divisions between the zero of the head scale and the edge of the arm D is the zero error. Note whether it should be added to or subtracted from the scale reading.

As most of the students find it difficult to calculate the zero error and hence to apply the zero correction to the observed reading, it is often convenient to take no account of this but proceed as follows :–

Experiment 6.—**To find the thickness of a glass slip by a spherometer.**

Apparatus. A spherometer, a glass slab, a glass slip.

Method. Before using a spherometer determine the value of graduations on the two scales. Find out how far the screw advances when the head is turned through one complete revolution. This gives us the pitch of the instrument. Usually this is ·5 mm. or 1·0 mm. Count the number of divisions on the circular disc. When the head is turned each division of its scale as it passes the edge D, indicates that the screw has made one-*n*th of its pitch, where *n* is the number of divisions on the edge of the large disc C. This quantity is the *smallest reading* or *least count* of the instrument.

Place the cover slip on the slab of glass and place a spherometer so that the central leg is on the glass slip and

the other three legs rest on the surface of glass **slab.** Read and note in your copy book the division on the horizontal disc which is opposite to the edge of the vertical scale. Let us suppose it to be 25. Next remove the glass slip and begin rotating the screw downwards. Go on counting the revolutions till the central leg touches the surface of the glass slab. Suppose 2 revolutions are given and 65th division on the disc comes opposite to the vertical scale. If the disc has 100 divisions on it, the number of divisions turned through $=2$ whole turns $+65-25=241$ divisions. If the pitch of the spherometer is ·5 mm. the least count is ·005 mm.

$\therefore$ Thickness of the plate $=241\times \cdot005$.

Take about five observations and record thus :

Number of obser-vations.	Number of revolutions.	Number of divisions on the circular disc.	Thickness of the glass slip	Mean thickness.

Precautions :—

1. See that the point of central leg of the spherometer just touches the surface of the glass slab.

2. Take the zero error into account.

Experiment 7. **To determine the radius of curvature of the surface of a lens or Mirror.**

Apparatus.—A spherometer, a concave mirror, a convex lens.

Method. Place the spherometer with the fixed feet resting on the concave or convex surface and adjust the central leg till it just touches the surface. Read the circular scale. Replace the instrument on the plane surface and find how many turns have to be made to bring the central foot back to the plane of the other three feet. From this and the reading of the circular head in the two adjustments, find out as in the last experiment, the distance through which the screw was moved. Take the mean of several readings and

hence get the mean value of h. Measure the distance between each of tne outer legs by passing them against a piece of paper and get the mean. Then the radius of curvature is given by the expression, $R=\frac{l^2}{6h}+\frac{h}{2}$.

Precautions :—1. Measure l very accurately as R depends upon the square of l, which means an error of double the magnitude.

2. If h is in millimetres, convert it to centimetres and measure l also in centimetres.

3. $\frac{h}{2}$ is usually small as compared with $\frac{l^2}{6h}$ and can be neglected. Record thus :—

Number of obser- vations.	Reading on the lens.	Reading on the plane surface.	Number of com- plete revolu- tions.	Number of divisions on the disc.	Height	Mean height

Distance between either of the outer feet=
(1) (2) (3) (4) Mean=

Proof of the formula $R=\frac{l^2}{6h}+\frac{h}{2}$.

Let the circle PBR be the section of a sphere by a vertical plane passing through the centre of the sphere (of which the lens forms a part), and one of the outer fixed legs which is resting at B and the central leg of the spherometer at P. B′ is another fixed leg. The movable central leg rests at P on the sphere, h above the plane of the three outer fixed legs. From the geometry of the figure, we have

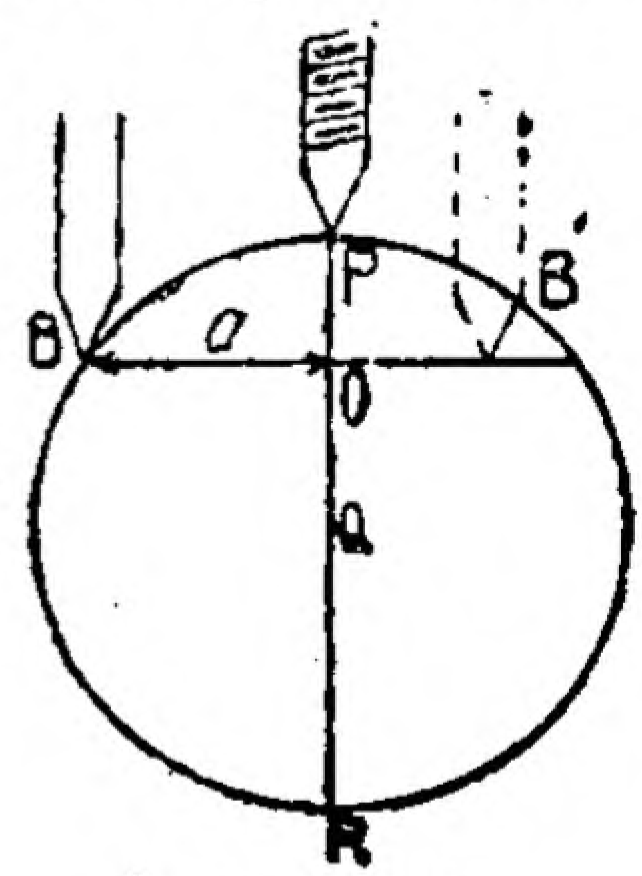


Fig. 21.

$$BO^2=PO\times OR=PO\ (PR-PO)$$
$$=h(2R-h),\text{ where }R=PQ,$$
$$\text{and }h=PO$$

But $BO=a \therefore a^2=h(2R-h)=2Rh-h^2$

or $$R=\frac{a^2}{2h}+\frac{h}{2}. \qquad \ldots(i)$$

Let ABC be the equilateral triangle formed by joining the three outer legs and let S be the point of the central leg when the four are in one plane. Since the central leg passes through the C. G. of the triangle formed by the three legs, the angle C is bisected by CS and the side AB is bisected by the line CSD at D.

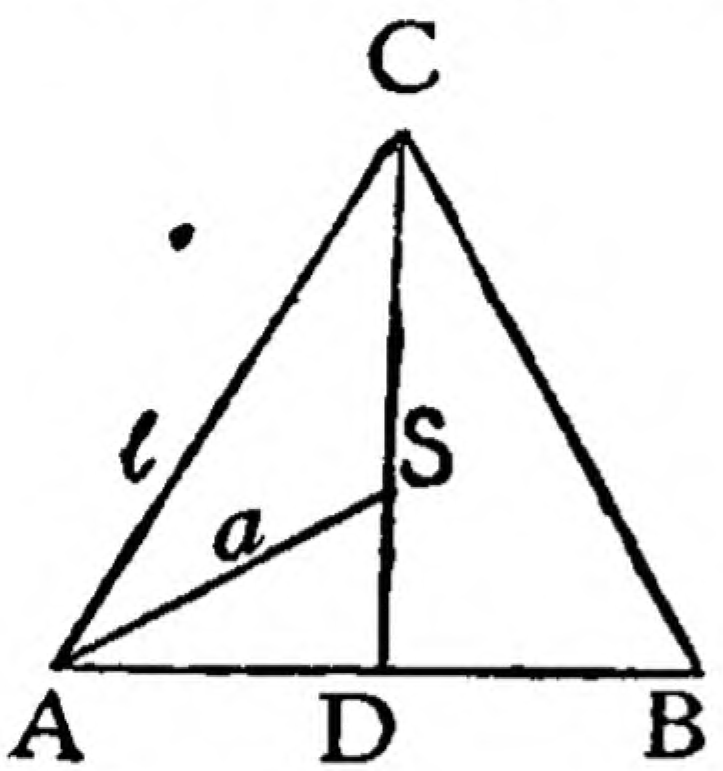


Fig. 22.

$$\therefore AD=\frac{l}{2} \text{ and } \angle DAS=30^\circ$$

$$\therefore \frac{l}{2}=a\cos 30^0=a\times\frac{\sqrt{3}}{2}$$

or $l^2=3a^2$ or $a^2=\frac{l^2}{3}$.

Substituting the value of a in (i) above.

$$R=\frac{\frac{l^2}{3}}{2h}+\frac{h}{2} \qquad R=\frac{l^2}{6h}+\frac{h}{2} \qquad \ldots(ii)$$

Formula (ii) is preferable as l is larger than a and can therefore be more accurately determined.

MEASUREMENT OF ANGLES

Unit of Angular Measurement. The general plan adopted in measuring angles is to divide a circle into 360 equal parts and to call each part a degree. Thus a movable hand pivoted at the centre of a circle has traced out an angle of one degree when it has gone round $\frac{1}{360}$th part of a complete revolution. When it has performed one quarter of its journey round, it has made an angle of ninety degrees, or a right angle as it is called.

The minute hand of a watch or clock moves through 360 degrees in an hour or ninety degrees in every quarter of an hour, and this is true whatever the size of the hand. This shows that the size of an angle is quite independent of the

length of the lines between which it is contained. All circles contain 360 degrees. All right angles contain ninety degrees. A degree is divided into 60 equal parts known as minutes, and again a minute is divided into 60 equal parts called seconds.

The magnitude of an angle can be found by means of a protractor. The simplest form of this is a semi-circle divided into degrees.

Use of a Protractor. Place the protractor with its straight edge over one of the arms of the angle. Adjust it so that the angle point lies exactly at the centre of the straight edge. Observe the position when the second arm cuts the semi-circle. Always try to take readings upto the tenths of a degree. If the arms are too short, produce them to a convenient length. If on the other hand, you want to obtain an angle by its use, place it so that its straight edge lies along the line. Keep the centre of the protractor at the point where you want the angle to be situated. Mark the centre and a point at the graduation you require. Join the two parts after removing the protractor.

Trigonometrical Ratios of an Angle. Let ABC be an angle. Drop a perpendicular AC from the point A to the arm BC. ABC is a right-angled △.

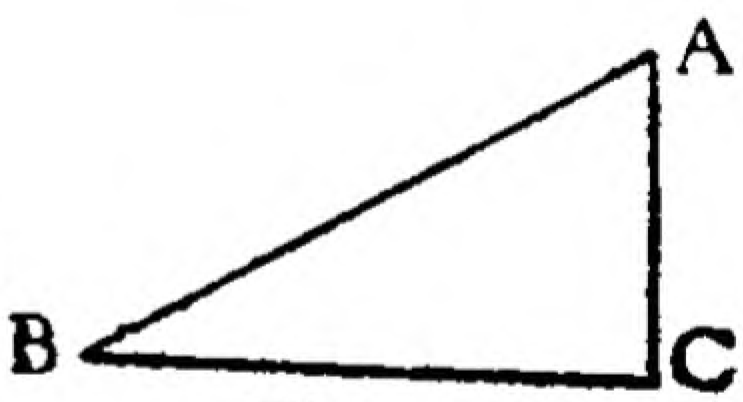


Fig. 23.

The different ratios of the sides of the △ are given the following names :

$$\frac{\text{Perpendicular}}{\text{Hypotenuse}}=\frac{CA}{AB}=\text{Sine of B or Sin B}$$

$$\frac{\text{Base}}{\text{Hypotenuse}}=\frac{BC}{AB}=\text{Cosine of B or Cos B}$$

$$\frac{\text{Perpendicular}}{\text{Base}}=\frac{CA}{BC}=\text{Tangent of B or Tan B}$$

$$\frac{\text{Hypotenuse}}{\text{Perpendicular}}=\text{Cosecant B.}$$

$$\frac{\text{Hypotenuse}}{\text{Base}}=\text{Secant B.}$$

$$\frac{\text{Base}}{\text{Perpendicular}} = \text{Cotangent B.}$$

These ratios are called the trigonometrical ratios of an angle. These ratios depend only on the magnitude of the angle and not upon the lengths of the arms of the angle. For, if the point A′ had been taken, still away from B and the perpendicular A′C′ be drawn to the arm BC of the angle B, then $\triangle$s BAC and BA′C′ are evidently similar Fig. 24.

$$\text{Hence } \frac{CA}{BA} = \frac{C'A'}{BA'} = \text{Sin B}$$

Thus Sin B is independent of the position of the point B. The same remark applies to the other ratios. The first three ratios are met with in Practical Physics. The trigonometrical ratios of any angle can be obtained from tables similar to logarithmic tables.

Experiment 8. **To measure a given angle by its trigonometrical ratios.**

Apparatus:—Protractor, drawing board, set squares, metre rod.

Method. Draw an acute angle B and from one of its arms draw a perpendicular AC to the other arm. Draw a second perpendicular A′C′ also. Measure the heights, bases and hypotenuses of the two right-angled triangles ABC and BA′C′ so formed. Again, from the point A″ on arm BC draw a perpendicular A″C″ on the arm BA meeting it at C″. Measure the base, height and hypotenuse of this triangle also.

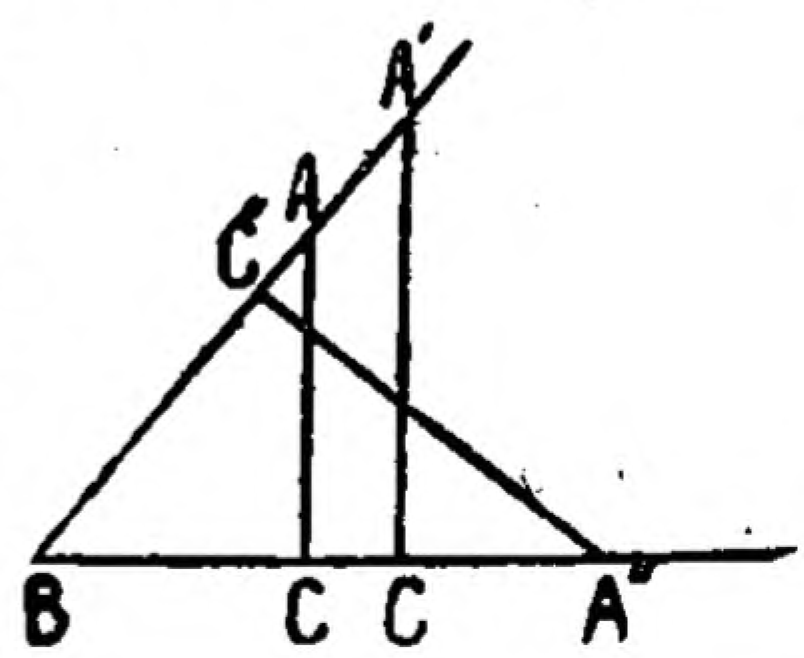


Fig. 24.

No of observation	Length of perpendicular.	Length of base.	Length of Hypotenuse.	Sin B = $\frac{\text{perp.}}{\text{hypo.}}$	Cos B = $\frac{\text{base}}{\text{hype.}}$	Tan B = $\frac{\text{perp.}}{\text{base.}}$	Radian.

The ratios in the last three columns would be found to be constant.

Precaution :—Measure the lengths by means of a scale placed edgewise.

Heights of Trees, Buildings, or Walls, etc. Suppose we want to find the height of a wall or tree. In order to do it, take a rod, and fix it vertically in a stand. Place the rod on the table (Fig. 25). Keeping the eye at the edge of the table move the rod along the table until its top comes just in line with the eye and top of the opposite wall. Now measure the distance of the edge of the table from the rod and the wall. Find out the exact length of the rod.

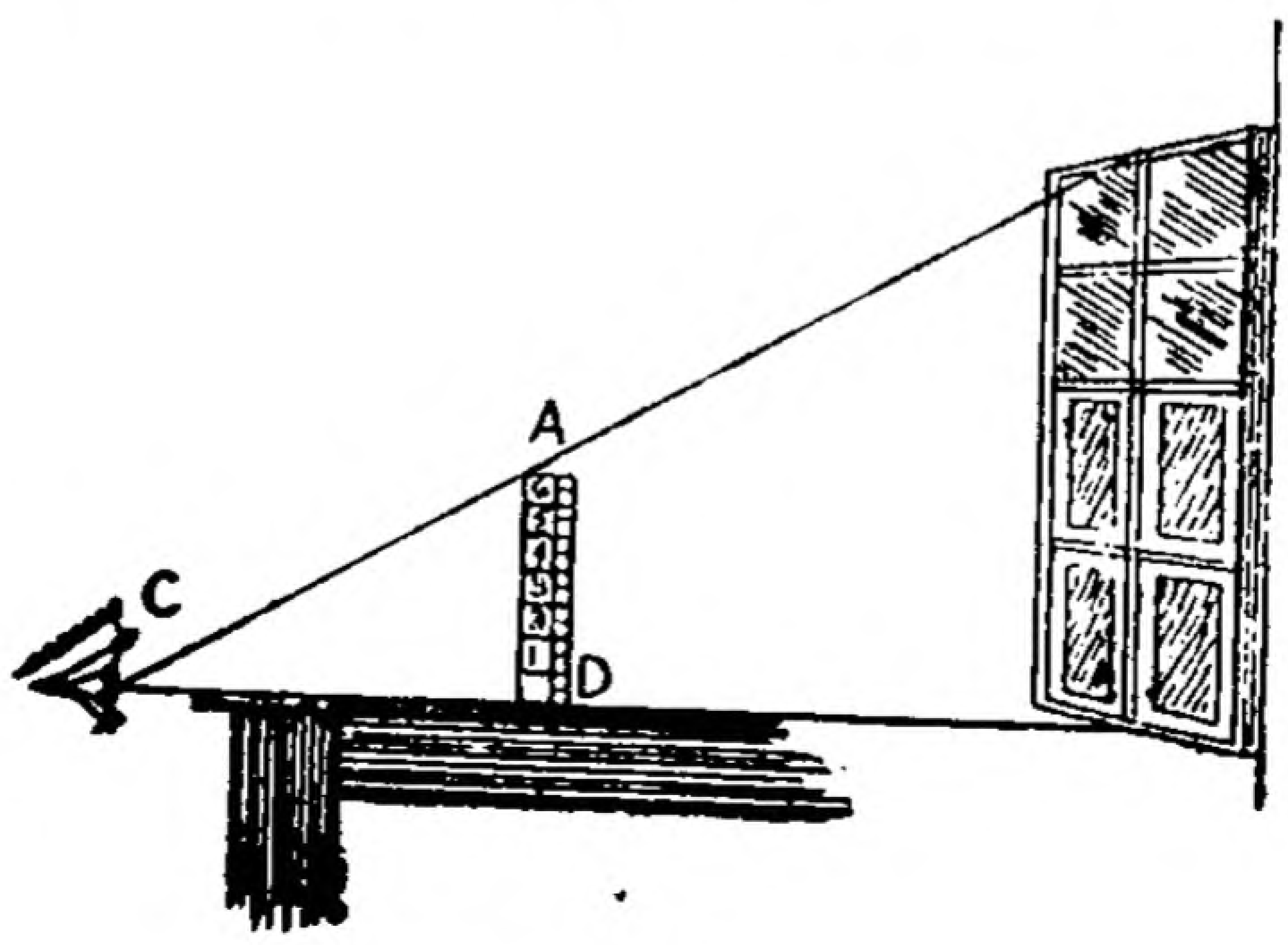


Fig. 25.

$$\text{Tan } \angle ACD = \frac{\text{Length of the rod}}{\text{Distance of the rod from the eye}}$$

$$= \frac{\text{Height of wall above the table}}{\text{Distance from the eye to the wall above the table}}.$$

The length of the rod and the distance of the rod from the eye must be measured with greater accuracy than the other distance.

Hence the height of wall above the table

$$= \frac{\text{Distance from the eye to the wall}}{\text{Distance from the eye to the rod}} \times \text{ the length of the rod.}$$

$\therefore$ Height of wall = Height of wall above table + height of table.

CHAPTER IV

MEASUREMENT OF AREA

In order to measure an area (or extent of the surface) it is not enough to measure one length only, two lengths must be considered, *viz.* length and breadth. It should be borne in mind that unavoidable errors in measuring a length are augmented considerably when two such observed lengths are multiplied together and that the product of the lengths may be greatly in error. Hence great accuracy should be observed in measuring these lengths.

Area of regular figures may be determined by measuring their linear dimensions :—

Area of a square $=(\text{side})^2$

,, rectangle $=$ length $\times$ breadth

,, triangle $=\frac{1}{2}$ base $\times$ height

,, circle $=\pi\ (\text{radius})^2$

,, parallelogram $=$ base $\times$ height.

Experiment 9. **To measure, the area of a circle by** (*i*) **squared paper,** (*ii*) **weighing, a d to verify that the area of a circle $=\pi r^2$.**

Apparatus.—Squared paper, compasses, thick paper, set squares, scissors.

Method. (*i*) Open the compasses by placing it on a metre rod so that the distance between its legs is exactly 5 cms. Draw a circle with this radius, the centre being at the inter. section of two heavy lines. The boundary of the circle should be well defined. Count the small squares within the circle ; take fractions which are more than one half within the boundary as complete and neglect those which are less than one half. Count the big squares and small squares **separately**.

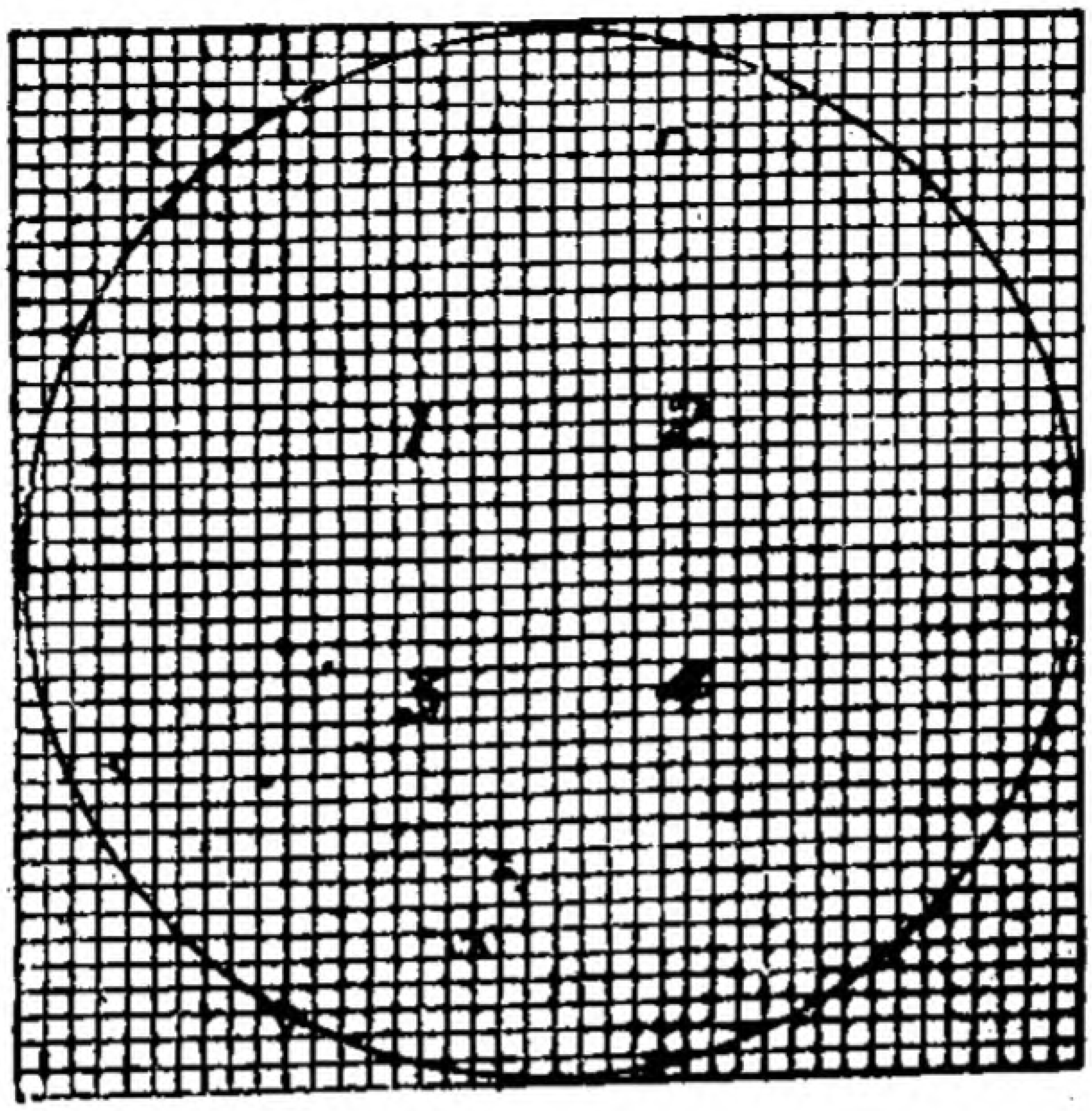


Fig. 26.

Record thus :—

Number of big squares= Area of the circle =

,, small squares = Radius ,, ,, =

Area by calculating with the formula πr^2=

(*ii*) Draw accurately on thick paper with pointed pencil, a square of 10 cms. side. Draw also on the same paper a circle of 5 cms. radius. Cut out accurately the square and the circle and weigh them separately. Divide the weight of the square by its area and get weight for 1 square cm. of area. Now divide the weight of the circle by the weight of 1 sq. cm. and get the area of the circle. Compare this result with the result obtained by calculation.

Wt. of circle = Area of square=

Wt. of square = Area of circle =

Precautions :—

1. The boundary of the figure should be fine and well defined.

2. Take fractions which are more than one-half within the boundary as complete and neglect those which are less than one half.

3. Count the big squares and small squares separately.

NOTE.—Test the square drawn by measuring its two diagonals. If they are equal, the square is correct.

CHAPTER V

MEASUREMENT OF VOLUME

Volume of Bodies of Regular Shape. The volume of bodies of regular shape can be determined by measuring their dimensions and applying the proper formula. Dimensions which are to be squared or cubed must be measured with great accuracy. Express the linear dimensions of the body in the same unit. The following are a few formulæ for the regularly shaped bodies :

Volume of a rectangular body $=$ length $\times$ breadth $\times$ height

,,	Cube	$=(\text{length})^3$
,,	Sphere	$=\frac{4}{3}\pi(\text{radius})^3$
,,	Cylinder	$=\pi\times(\text{radius})^2\times\text{length}$
,,	Cone	$=\frac{1}{3}\pi(\text{radius})^2\times\text{height}.$

For bodies of irregular shape, determine the volume by the following methods :

1. (*a*) By immersing it in water contained in graduated jars, (*b*) By the use of burette as is explained below.

2. By the application of the principle of Archimedes, *viz.*, when a body is immersed in a liquid it loses a weight equal to the weight of the volume of the liquid displaced. We shall describe in this chapter the first method the second being described in the next Chapter.

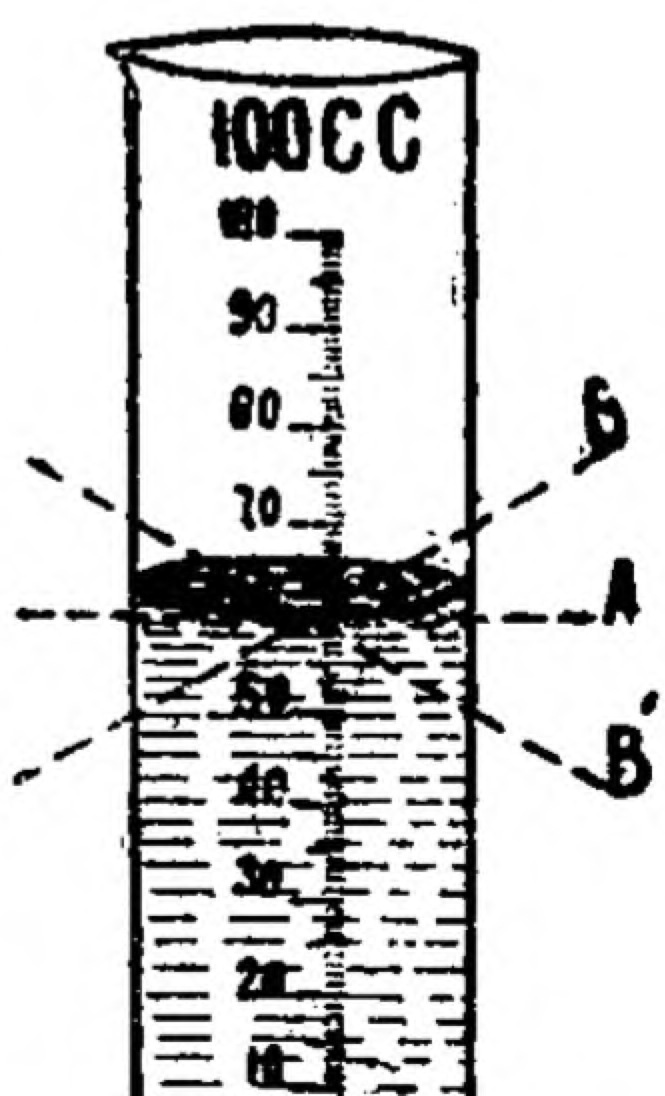


Fig. 27.

Graduated jars. The figure opposite shows a graduated cylinder on which the graduations indicating different volumes of the liquid that it contains (when filled up to different points) are marked on the glass. Pour water into such a cylinder and note that the liquid surface is not flat but curves up at the sides like a saucer. The curvature is called meniscus

and is produced by the surface tension of the liquid. Read the level at the bottom of the meniscus, *i. e.*, at the middle point of the liquid. In the figure A shows the correct position of the eye while B and B′ show the incorrect positions for reading the meniscus.

Burette. It is a finely graduated tube, graduated from the top, downwards to the tenth of a cubic centimetre. At the bottom is a tap or pinch cock (a rubber tube and clip) for allowing the liquid to flow out. On filling the burette first with the liquid the tap or clip should be opened till all the air is expelled from the exit tube. *Clamp the burette always in the vertical position.* This can be done either by comparing the edges of the burette with vertical edges of the walls or more correctly with a plumb line.

Experiment 10. **To find the volume of an iron nail.**

Apparatus.—Burètte, graduated jar, small beaker, a paper strip.

Method. Wash the burette and the graduated jar with caustic soda solution and rinse thoroughly. This is necessary because the water surface is deformed in greasy vessels and readings cannot be taken accurately.

Put enough water in the graduated jar, and place your eye at the same level as the water surface. Use a white paper behind the jar to read the position of the lowest point of the curved surface (tangent to the meniscus.) Estimate the tenths of the smallest division accurately. Drop in gently from 50 to 100 nails in the jar and read the meniscus again. The difference in the two readings gives the volume of the nails dropped. Divide this volume by the number of nails dropped to get the volume of one nail.

Precautions :—

1. Wash the burette and the graduated jar with caustic soda solution and rinse thoroughly.

2. Place your eye at the same level as the water surface and read the position of the lowest point of the curved surface.

3. Try to estimate the tenths of the smallest division accurately.

4. Adjust the burette vertically and bring the level of water at zero or at some other convenient division, say 2 c.c. Take a small beaker, put in it gently from 50 to 100 nails and take it underneath the burette. Allow the water to flow out of the burette quickly at first, drop by drop later on and stop the flow when the meniscus in the beaker is just above the surface of the nails. Now paste a strip of paper (by means of gum) so that the lower surface of the strip touches the meniscus in the beaker.

Read the burette carefully upto the tenth part, keeping the eye in the same level.

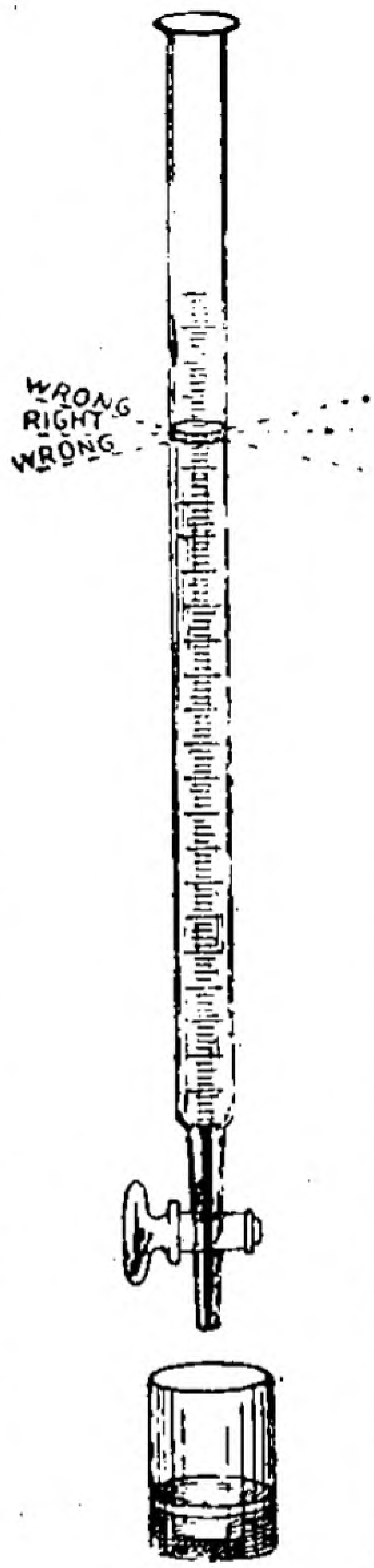


Fig. 28

Empty the beaker of its contents and dry it. Fill the burette again up to the same mark as before. Replace the beaker underneath the burette. Allow water to flow out of the burette as before quickly at first, drop by drop later on and stop the flow when the meniscus in the beaker coincides with the lower edge of the gum paper. Read the burette carefully upto the tenth part keeping the eye in the same level.

The difference between the two readings gives us the volume of the iron nails taken. Repeat the experiment and take the mean of two or three readings.

Record thus :—

No. of observation	With nails		Amount of water run in	Without nails		Amount of water run in	Volume of iron nails
	Initial reading of burette	Final reading of burette		Initial reading of the burette	Final reading of the burette		

Volume of one nail =

Precautions:—1. Remove the air bubbles from the nails and from the inside of the beaker and burette.

2. The eye should be kept at the same level while taking the observations in order to avoid error of parallax. Figure 28 shows the right and wrong positions of reading the burette.

Experiment 11. **To test the accuracy of the given burette.**
Apparatus.—Burette, a burette stand, beaker, thermometer, small funnel, plumb line.

Method. Fill the burette and adjust it in the vertical position in the clamp. Bring the level of water in the burette to stand at zero mark and allow the excess of water to flow through the stopper or pinch cock. Weigh a small empty beaker and place it under the burette. Allow the water to run out quickly at first, drop by drop afterwards till the burette reading is 10 c. cs. Allow the last drop sticking at the end of the burette to flow into the beaker. Note the temperature of water in the burette. Weigh the beaker. Find out the density of water at the temperature from the tables. Again place it under the burette and run in 10 c.cs.

more. Weigh this water also. Go on running 10 c. cs. of water like this each time and weighing the beaker every time. The first weight subtracted from the second weight each time gives the weight of the water run in.

Take about 5 such observations. Divide each of these weights by the density at that temperature and get the volume. Compare this volume with the volume obtained from the burette reading.

Record thus :—

Weight of the beaker=

No. of observation.	Initial reading of burette.	Final reading of burette.	No. of c.cs. run in.	Weight of water.	Volume of water calculated by dividing the weight by density.	Error.

Precautions :—Observe the same precautions as observed in the last experiment.

Mohd.

CHAPTER VI

MASS, OR WEIGHT AND DENSITY

The mass of a body can be obtained by comparing it with standard masses called weights. Just as in measuring lengths it is necessary to have a standard with which to compare, so in measuring masses there must also be a standard or unit. The standard adopted is the Kilogram. It is the amount of matter contained in a lump of platinum which is kept safely at Severs. It is heavier than the British pound.

It is interesting to know how the mass of a Kilogram was derived. The mass of the piece of platinum was made equal to that of one thousand cubic centimetres of water, *i.e.*, of a litre of water at a particular temperature. A thousandth part of Kilogram is called a gram. It is in terms of grams that we usually measure mass.

The weights in terms of which we express our masses are usually made of brass and are contained in holes in

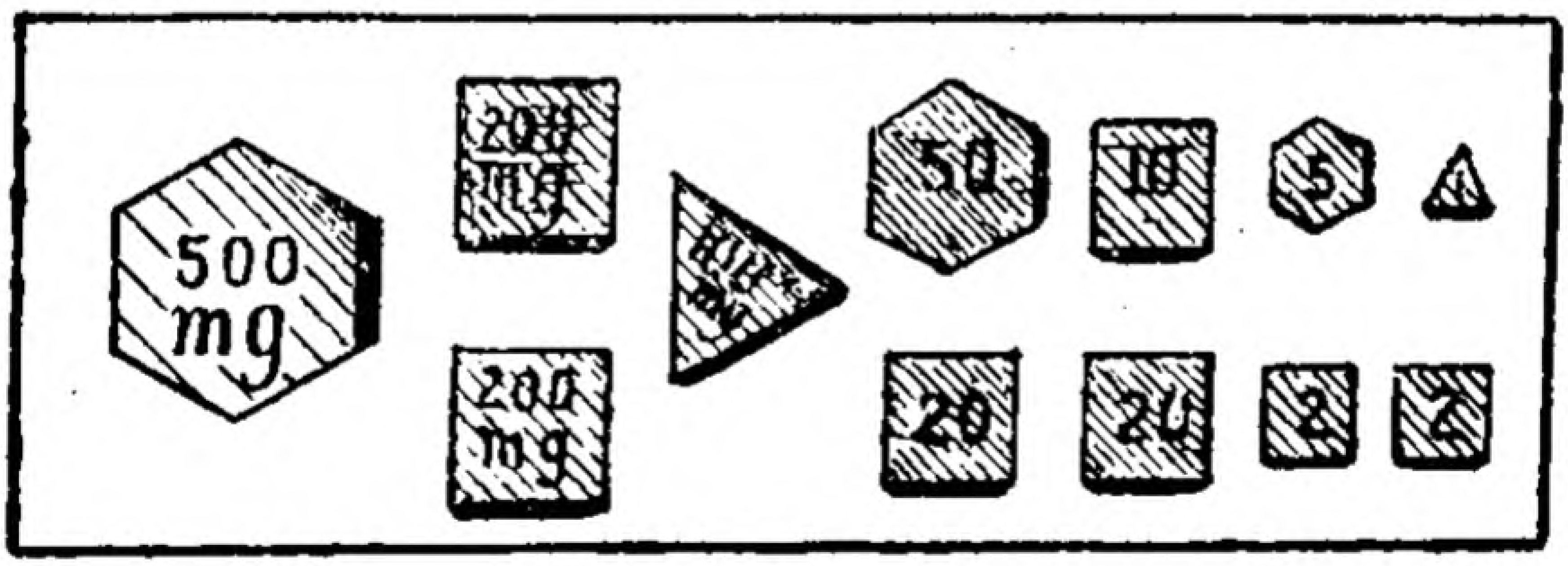


Fig. 29.

wooden boxes. These are from 1 gram upwards. The fractions from ·5 to ·001 gms. are generally made of aluminium and along with a pair of forceps are contained in the same box. As is often the case, the students lose their fractional weights, hence it is better if they are required to purchase their own fractional weights.

The common balance.—The ordinary balance consists of a stiff beam usually of girder construction. It is supported

at its centre on an agate or steel knife edge which rests on a flat agate plate at the top of the pillar. There are two

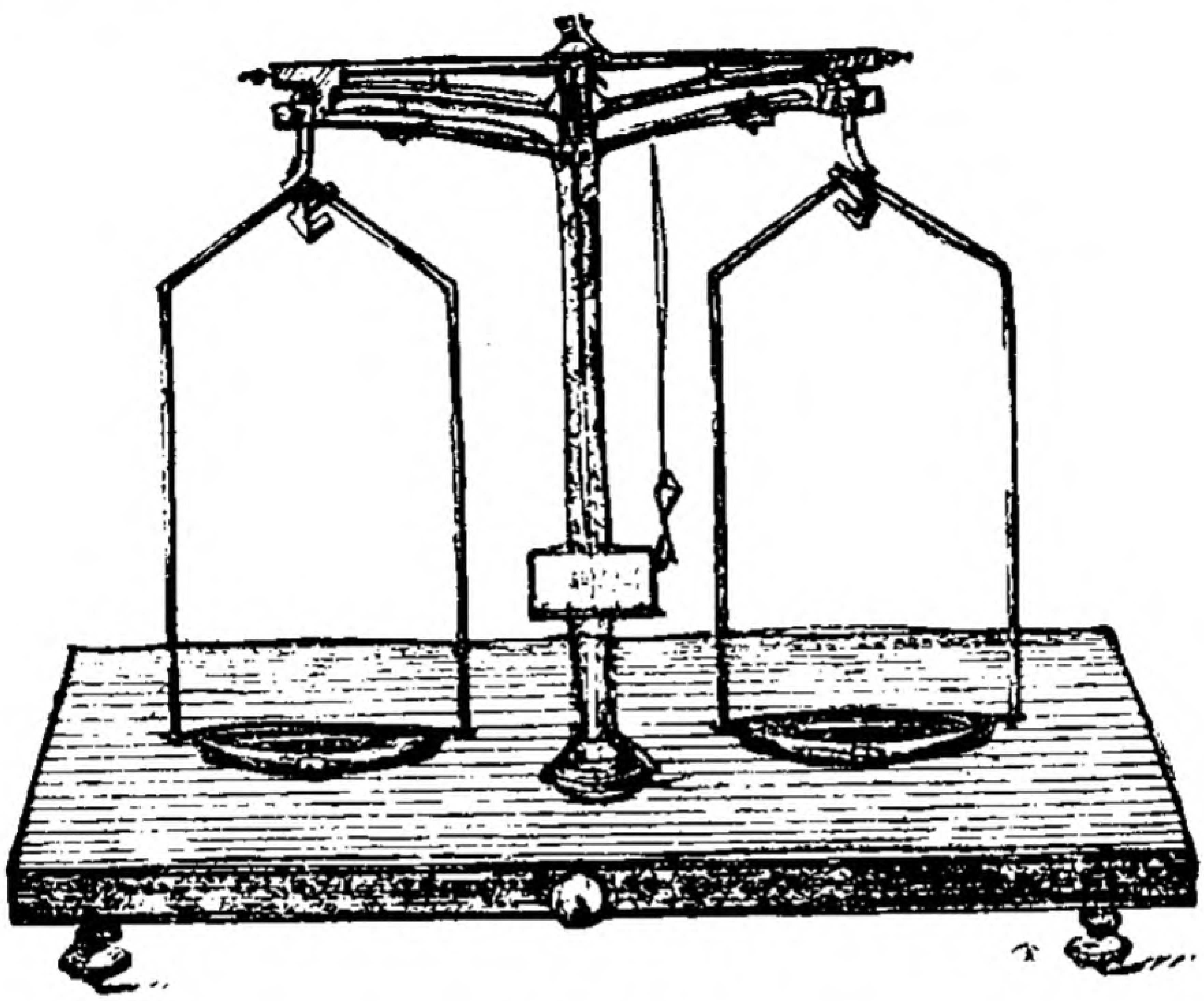


Fig. 30.

other similar knife edges at the ends of the beam. These end knife edges point upwards and support the stirrups from which hang the scale pans. These stirrups are fitted with slightly curved agate plate. To the middle of the beam is attached a pointer which swings in front of an ivory scale of equal parts fixed at the foot of the pillar. The scale is marked on both sides of the zero, which is in the middle. The pointer would stand at zero if the beam is horizontal. There is fixed a screw stem at each of the beam on which travels a nut. By turning these nuts, the pointer is displaced in a direction opposite to their motion. If the pointer does not make equal swings on the two sides of the zero, adjust carefully the small nuts at the end of the beam till the swings are very nearly equal. The beam can be slightly moved up and down by means of the milled head or lever provided. When the balance is not working the beam does not rest at the knife edges but on supports which protect the knife edges from having undue pressure and thus losing their sharpness. The balance is said to be in perfect work-

ing order if when the beam is raised by the milled head the pointer oscillates equally on both sides of the zero if the pans are unloaded and beam free. The swinging of the pointer gradually diminishes until it comes to rest. *The scale division in front of which the end of the pointer comes to rest is called* **the resting point.** When the pans are unloaded the resting point in a balance which is in perfect working order would be zero. If the pans are loaded then to determine the resting point it is not necessary to wait till the pointer comes to rest but note the turning on the scale division on the right or left. Take the mean of three divisions (readings) on one side and two on the other as your resting point.

Set of metric weights.—Set of metric weights are marked usually in grams and milligrams and a complete set will include the following :—

(1) Brass weights : 100 gms., 50 gms., 20 gms., 20 gms., 10 gms., 5 gms., 2 gms., 2 gms., 1 gm.

Aluminium weights.

500 m. gm. = ·5 gm.	50 m. gm. = ·05 gm.
200 m. gm. = ·2 gm.	20 m. gm. = ·02 gm.
200 m. gm. = ·2 gm.	20 m. gm. = ·02 gm.
100 m. gm. = ·1 gm.	10 m. gm. = ·01 gm.
5 m. gm. = ·005 gm.	5 m. gm. = ·005 gm.
2 m. gm. = ·002 gm.	2 m. gm. = ·002 gm.
1 m. gm. = ·001 gm.	

By means of this set, any weight which is a multiple of 1 m. gm. and does not exceed 210 gms. may be obtained.

The box contains a pair of forceps which must be used always when weights are removed from or replaced in the weight box. The weights are used in the following manner. The object to be weighed is placed on the left pan and such weights as are estimated as sufficient to counter-balance the object are placed in the right pan. Suppose that 20+10 gms. are used and that on slightly releasing the beam, the pointer moves towards the object, these weights are evidently too great. The 5 gms. weight is substituted for the 10 gms. wt., if this is now too small, the second 2 gms. wt. is added. The subsequent steps are as follows :—

20+5+2 too small
20+5+2+1 too small

$20+5+2+1+0{\cdot}5$ too small
$20+5+2+1+0{\cdot}5+0{\cdot}2$ too great
$20+5+2+1+0{\cdot}5+0{\cdot}1$ too great
$20+5+2+1+0{\cdot}5+0{\cdot}5$ app. constant.

The weight is thus found to be 28·55 gms.

Special precautions in weighing :—

1. By means of the plumb line see that the balance is in level.

2. See that the stirrups are not displaced. See also that the pans are dry and clean.

3. Lower the arrestment to see whether the pointer swings equally on both sides of the middle point of the scale. If necessary adjust the balance by means of the nuts at either end of the beam.

4. Do not stop the swinging of the balance with a jerk but stop it gently when the pointer is nearly at its central position.

5. Place the body to be weighed on the left-hand pan and the weights on the right-hand pan.

6. Lower the arrestment before adding or removing any weight.

7. Manipulate the arrestment with the left hand and convey weights with the right hand, *but always use the forceps.*

8. Do not weigh a body when hot : the heat causes air currents which affect the weighing.

9. Close the balance case when observing the swinging of the pointer and keep the case closed when the balance is not in use.

10. Always replace such weights in their proper compartments in the box.

Exercise.—Determine the ratio between the weights of a half anna copper piece and a pice.

Weighing by the method of oscillations.—If a balance is correctly adjusted the number of divisions through which the pointer will move would be equal on both sides of the midddle point of the scale. In an actual balance this is seldom true. It is also seen that when a balance is set swinging, the pointer will continue to move across the scale for a long time and we shall have to wait for a long time till it comes to rest, hence in all weighing resting point is determined when the pointer is oscillating.

Experiment 12 **To find the resting point of the given balance and to weigh the given object by the method of oscillation.**

Apparatus.– Balance, weight box, glass stopper.

Method.—Let the figure represent the scale.

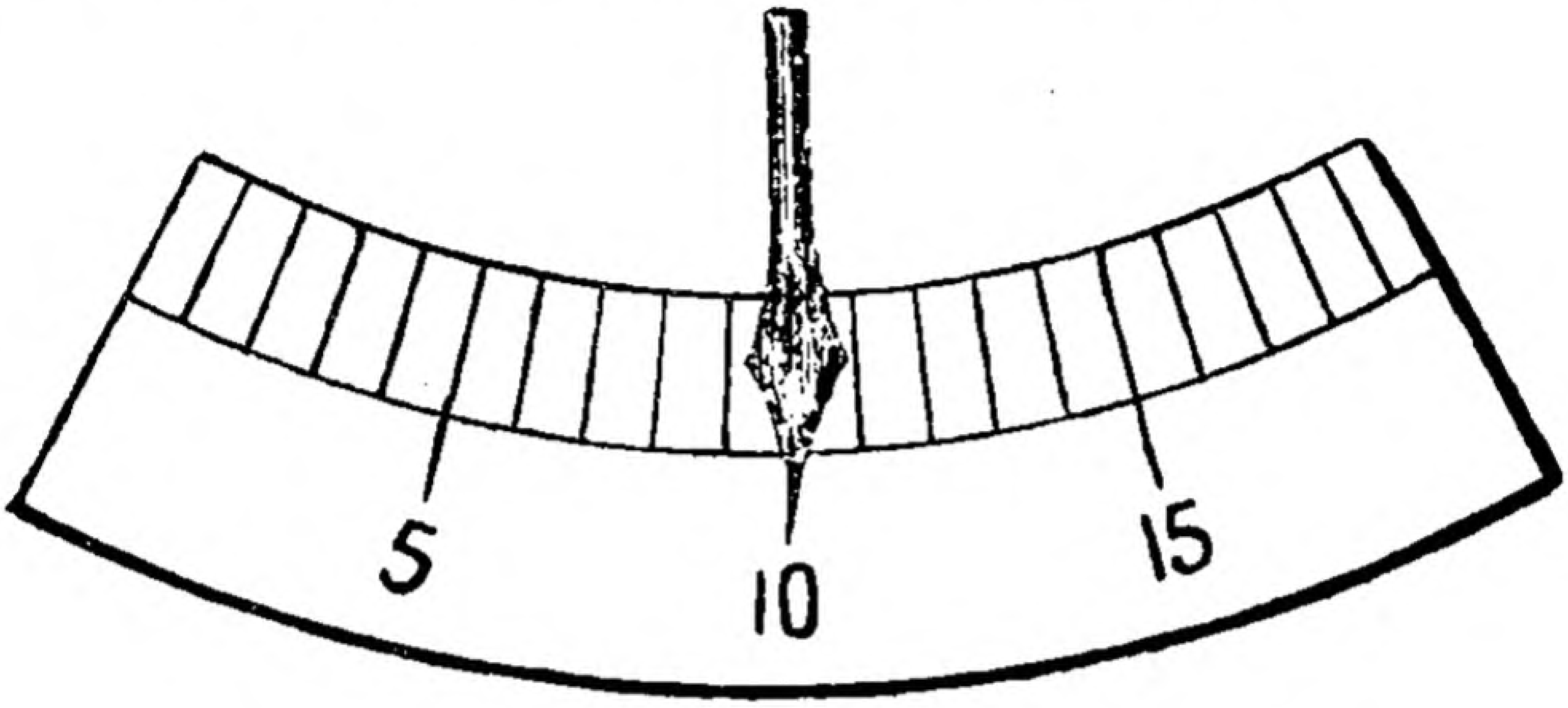


Fig. 31.

Now reckoning from the left we call the divisions, 0, 5, 10, 15 and 20. To determine the resting point, the beam is released, given a slight oscillation over about 5 divisions of the scale on each side of the middle point. Observe 3 consecutive turning points 2 to the left and one to the right or *vice versa*.

Reading to the left.	Reading to the right.
8·4	12·4
8·8	

Mean of the reading on the left side= 8·6
right side=12·4

Resting point=10·5

Repeat this step two times more and take the mean of three results. Next, place the object to be weighed in the left-hand pan and balance it with weights, while doing this see that the pointer does not go off the scale. Suppose that with 42·575 gms. the pointer moves to the right showing that the weight is too little. Find the resting point as before, suppose it to be 12·0. Now with empty pans the resting point is 10·5 while with 42·575 gms. the resting point is 12·0. Hence we want to find what is the exact wheight that we

must add to 42·575 gms. to bring the resting point from 12·0 to 10·5, *i.e.*, through 1·5 divisions. Now add 5 milligrams to the right-hand pan and find out the resting point again. Let it be 5·5. Now we know that the addition of 5 milligrams shifts the resting point through 5 divisions, therefore the weight required to produce a shift of 1·5 divisions, *i.e.*, to get the same resting point as with empty balance, is ·0015 gm. Thus the weight of the body is 42·575+·0015 or 42·5765 gms.

Precaution.— Take the readings of the resting point of the pointer when the pointer is moving over the middle of the scale.

The Spring Balance.—When we do not want to weigh a body accurately we make use of what is known as the spring balance. It consists of a spiral of steel wire, whose upper end is fixed to a ring and to the lower end is attached a piece of steel which ends in a hook to carry the body to be weighed. The spring is contained in a semi-cylindrical case and has a plate in front of it which is graduated. There is a long narrow slit in the rectangular plate. When the spring is pulled down, an index which is attached to the spring travels over the graduated scale.

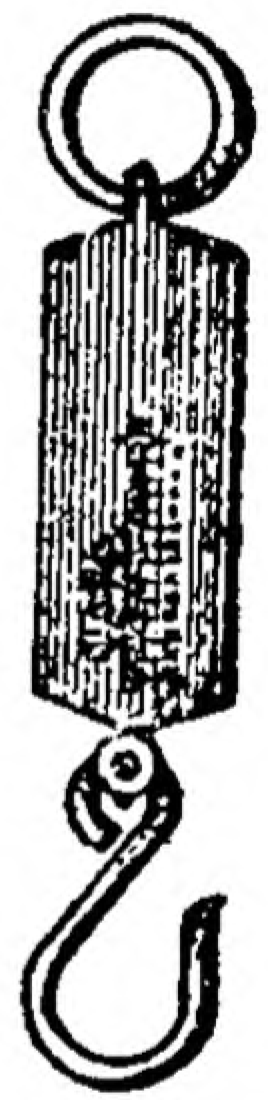


Fig. 32.

Exercise.—Weigh a given copper cylinder with the spring balance and compare the result got with common balance.

DENSITY

Different solids of the same size or volume may have different masses. Suppose for instance, determinations are made of the mass of a cubic centimetre of wood, lead, cork, and marble, one after the other. The lead will be found to have the greatest mass or to be the heaviest. The marble will come next, and then will follow the wood and cork in this order. In fact the heavier a substance, is the greater is said to be its density. Hence density is the mass per unit volume, *i.e.*, mass of a unit volume of the substance. If M be its mass and V its volume,

then $$D = \frac{M}{V} \text{ or } M = VD \text{ or } V = \frac{M}{D}.$$

Density is expressed in grams per cubic centimetre or pounds per cubic foot but in scientific measurement, it is always expressed as grams per cubic centimetre.

Determination of density :—

$$\text{Density} = \frac{\text{Mass of the substance in grams}}{\text{Volume of the substance in c. cs.}}$$

To determine the mass, we make use of the balance. We weigh the body in air by a balance. The volume, however, may be determined as follows :—

1. If it is a *regular body* its volume can be calculated by making use of the formula of measurements, for instance, if it is a sphere its volume will be $\frac{4}{3}\pi r^3$ or if it is a cylinder its volume will be $\pi r^2 \times h$, and so on.

2. If it is an *irregular body* its volume can be determined by putting it in graduated cylinder, which contains a liquid upto a certain mark. As soon as a body goes into the liquid, it displaces the liquid which rises in the cylinder. Noting the difference between the two graduations we get the volume.

3. The volume can be determined with the help of a *burette* and a beaker as already explained.

4. If the irregular solid be *lighter* than the liquid used, it is necessary to use a heavier body whose volume is known along with the given solid to make it sink. The combined volume can be determined by any of the two methods given above and subtracting from this the known volume of the heavy body we get the volume of the irregular body.

Experiment 13. **To determine the density of a copper cylinder by weighing it and finding out its volume by measurement.**

Apparatus.—A copper cylinder, vernier calipers, weight box and balance.

Method. Weigh carefully the given body in air. Record its weight. Measure by means of a vernier calipers its diameter and length. Now applying the formula $\pi r^2 \times l$ find out its volume in c.cs. Repeat the measurement of diameter from several places and find out the mean.

Record your observations thus :—

Weight of the cylinder in air=

No. of observation	Length of the cylinder	Diameter of the cylinder	Mean diameter	Radius	Volume $\pi r^2 \times l$	Density $=\frac{M}{V}$

Exercise —Find the density of a wooden sphere by weighing it and measuring its diameter by calipers.

Determination of Specific Gravities.—The Specific Gravity or Relative Density of a substance is defined as the ratio of the weight of any volume of that substance to the weight of an equal volume of same standard substance. The standard substance usually chosen is water. But the density of water is different at different temperatures, the maximum density being at 4°C (because 1 gm. of water at 4°C is one c.c.). Hence for accurate determination it is necessary to specify the temperature at which the measurements are made and a correction should be applied by multiplying the result by the density of water at the temperature.

The following table shows the density of water between 0°C and 50°C, density at 4°C being taken as unity:—

Temperature	0	1	2	3	4	5	6	7	8	9
0°C	0·99987	993	997	999	1	999	997	993	988	981
10	0·99973	963	953	940	927	913	897	880	862	843
20	0·99823	802	780	756	732	707	681	654	626	597
30	0·99567	537	505	473	440	406	371	336	299	262
40	0·99224	186	147	147	066	025	982	940	896	852
50	0·98807									

Note.—In consulting these tables remember to prefix ·99 to the figures in the columns 1, 2, 3, 4, 5, 6, 7, 8 and 9, except to those under 6, 7, 8 and 9 against 40°C, in which case ·98 are to be prefixed.

Principle of Archimedes.—The principle of Archimedes may be stated as follows :— "When a body is immersed in a fluid its weight apparently is diminished by the weight of the fluid displaced," or we can state thus :—"When a body is wholly or partially immersed in a fluid at rest it experiences an upward thrust equal to the weight of the fluid displaced."

Experiment 14.—**To verify the principle of Archimedes.**

Apparatus.—A hollow cylinder and a solid one fitting into it, both with hooks, a glass beaker containing water, a balance, wooden bridge, weight box, lead shots, vernier, callipers, kerosene oil, thermometer.

Method. Take two cylinders, one hollow and the other solid. The solid one should completely fit in the hollow one.

Both the cylinders should have hooks. Suspend the solid cylinder underneath the hollow cylinder and hang both of them from the beam of a balance. In hydrostatic balance generally used they are hung from the shorter pan by means of a piece of thread or very fine brass wire ; the solid cylinder is hung freely underneath the hollow cylinder. Take a wooden bridge and place it across the left hand pan of the balance. Take an empty beaker and place it on the bridge. The beaker should be small enough to go between the pan supports.

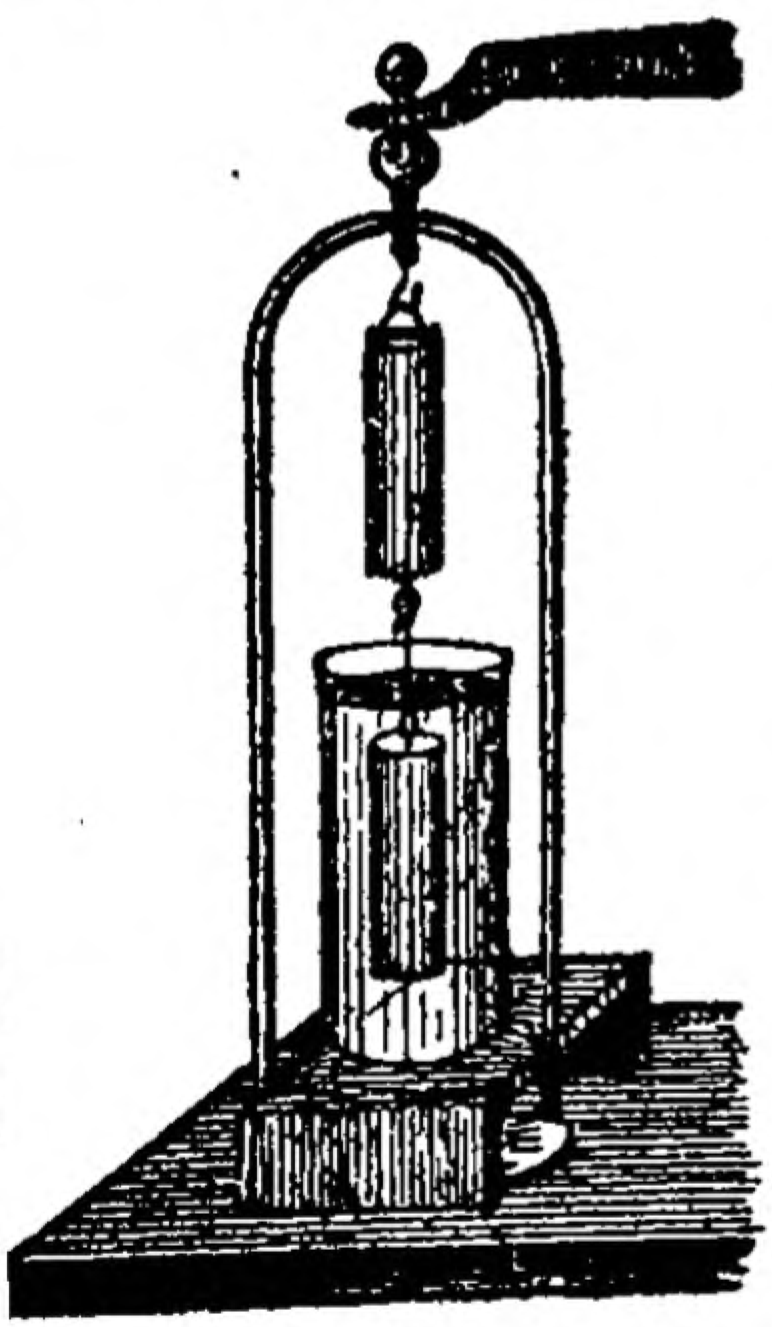


Fig.33.

Suspend the hollow cylinder from the pan of the balance and tie one end of the thread to its hook at its lower end. Tie at the other end of the thread the hook of the solid cylinder. Let them be suspended as shown in the figure 33. Counterpoise by putting weights in the other pan. Put water in the beaker so that the soild cylinder is well within water. Remove any air bubble sticking to the solid cylinder. It will be seen that the beam is no longer horizontal, the counterpoising weight being too great. Remove weights till the beam is horizontal. The loss in weight suffered by the solid cylinder when immersed in water is given by the weights removed. Now fill

the hollow cylinder with water; the equilibrium will again be disturbed. Add the same weight which you removed previously. The beam will be horizontal and the pointer will come to zero. This shows that the loss in weight is equal to the weight of an equal volume of water. Calculate the volume of the solid cylinder by measuring its length and diameter with vernier calipers. Record the temperature of water. Multiply the volume by the density of water at that temperature, the product is the weight of an equal volume of water.

Using kerosene oil repeat the whole experiment as above. The loss in weight in kerosene oil would be equal to the volume of the cylinder multiplied by density of the kerosene oil.

Record your observations as follows :—

Density of water at t^0C=

	Weights removed when the solid cylinder was in the liquid.	Weights added to the pan when the hollow cylinder was filled with the liquid.	Radius of the cylinder.	Length of the cylinder.	Volume of the cylinder.	Volume of the cylinder × density of liquid at that temp.
Water		1 6 2 7 3 8 4 9 5 10 Mean=	1 2 3 4 5 Mean=			
Kerosence oil.						

Alternative Method.

Take a metallic cylinder and suspend it from the pan of the balance (as in the previous experiment). Find out its weight in air. Now weigh this cylinder in water. See that the cylinder is well within water and does not touch the sides of the beaker. Remove any air bubbles sticking to the solid cylinder. The cylinder when so weighed will lose some weight. The loss in weight divided by the density of water at the temperature will give us the volume of the cylinder. The volume of the cylinder can be found out by measuring its diameter and length by means of calipers. The diameter should be measured from different positions at least ten times and the length thrice. Then applying the formula $\pi r^2 \times l$, the volume can be calculated. l is the length and r the radius of the cylinder. Using kerosene oil repeat the whole experiment as above.

Record your observations thus :—

	Wt. of the cylinder in air.	Wt. of the cylinder in the given liquid.	Loss of wt. in the liquid.	Density of the liquid.	Volume $= \frac{\text{Loss in wt.}}{\text{Dety of liquid}}$	Radius of the cylinder.	Length of the cylinder.	∴ Volume of the cylinder $= \pi r^2 \times l$
Water						1 6 2 7 3 8 4 9 5 10 Mean =	1 2 3 Mean =	
Kerosene oil.								

Precautions.—1. While weighing observe the precautions given on page 63.

2. Apply the temperature correction, *i. e.*, multiply by the density of liquid at that temperature in first experiment.

3. Cut off all knots and superfluous thread.

4. See that the solid cylinder is well within water and that it does not touch the sides of the beaker.

5. Remove all bubbles sticking to the sides of the cylinder.

Experiment 15.—**To find the length of a given tangle (coil) of wire without unfolding it.**

Apparatus.—A coil of wire, fine silk thread, screw gauge, balance, weight box.

Method.—Suspend the given coil of wire by means of a fine silk thread from the hook of the left-hand pan of the balance. Weigh it accurately. Place a wooden bridge across the left hand pan and above it a beaker about $\frac{3}{4}$ full of water. Find the weight of the coil in water. Calculate the loss in weight. Remove the silk thread from the coil and by means of a screw gauge measure its diameter at several different places because the wire may not be uniform in its thickness and may not have a uniform cross-section.

Record thus :—

Density of water at t°C=

Weight of the coil in air.	Weight in water.	Loss of weight.	Volume of the coil.	Diameter	Area of cross-section.
			$=\frac{\text{Loss of weight}}{\text{Density of water}}$	1 6 2 7 3 8 4 9 5 10 Mean=	

But we know the volume of the wire=its length × area of cross-section.

$$\text{Hence length}=\frac{\text{volume}}{\text{area of cross-section}}.$$

Precautions.—

Observe the following precautions in addition to what are given in experiment 14.

1. Weigh the body with the shutter of the balance closed.

2. Before using the screw gauge note down its zero error, if any.

Exercise.—Find the volume of a given copper cylinder by applying the principle of Archimedes.

Experiment 16 (1) **To determine the specific gravity of glass, using a glass stopper.**

(2) **To find the specific gravity of turpentine oil.**

Apparatus.—A glass stopper, fine thread, beaker, a bridge, balance, weight box, etc., etc.

Method.—Suspend the glass stopper with a thread as in previous experiment and determine its weight in air. Let it be (W). Next, allow it to be immersed in water as in the previous experiment and let its weight be W_1. Determine the loss of weight. Record your observations as follows :—

Specific gravity of the stopper $= \dfrac{W}{W-W_1} \times$ density of water at that temperature.

(2) Weigh the stopper in air and then weigh it in water as in the previous experiment. Find out the loss in weight. Note the temperature of water. Pour off water from the beaker and wipe it quite dry. Dry the stopper and the piece of thread. Now fill $\frac{3}{4}$ of the beaker with turpentine oil and by repeating the experiment as with water, find out the loss of weight.

Record thus :—

Weight of the glass stopper in air $= W$
" " " " in water $= W_1$
Loss of weight in water $= W - W_1$
Temperature of water =
Temperature of turpentine =
Weight of the stopper in turpentine $= W_2$
Loss of weight in turpentine $= W - W_2$
Specific gravity of turpentine oil

$$= \frac{\text{Loss of weight in turpentine oil}}{\text{Loss of weight in water}} \times \text{Density of water}$$

at the temperature.

Precautions.—Observe the precautions given in experiment 14. The stopper should be wiped dry before being put in the next liquid.

Exercise.—Determine the specific gravity of a crystal of common salt or a crystal of sugar.

Hint.—If the substance is soluble in water, find its relative density in a liquid which does not dissolve the solid and multiply the result by the density of that liquid (which can be determined separately). This will give the specific gravity of the substance as is proved below :—

Loss of weight in oil=weight of v. c. c. of oil (where v stands for the volume of the substance) $= v \times$ density of oil.

$$\therefore v = \frac{\text{Loss of weight in oil}}{\text{Density of oil}} \qquad \ldots(1)$$

But density of the solid $= \dfrac{\text{Weight of the solid}}{\text{Volume of the solid}} \qquad \ldots(1)$

Substituting the value of the volume from (1) above in (2)

The density of the solid $= \dfrac{\text{Weight of the solid}}{\text{Loss of weight in oil}} \times$ density of oil.

Experiment 17.—**To find the specific gravity of a solid lighter than water (a piece of a wood or cork).**

Apparatus.—A piece of wood or cork, sinker, beaker, weight box, slik thread.

Method.—Weigh the solid in air by suspending it with a thread from the hook of the pan of a balance.

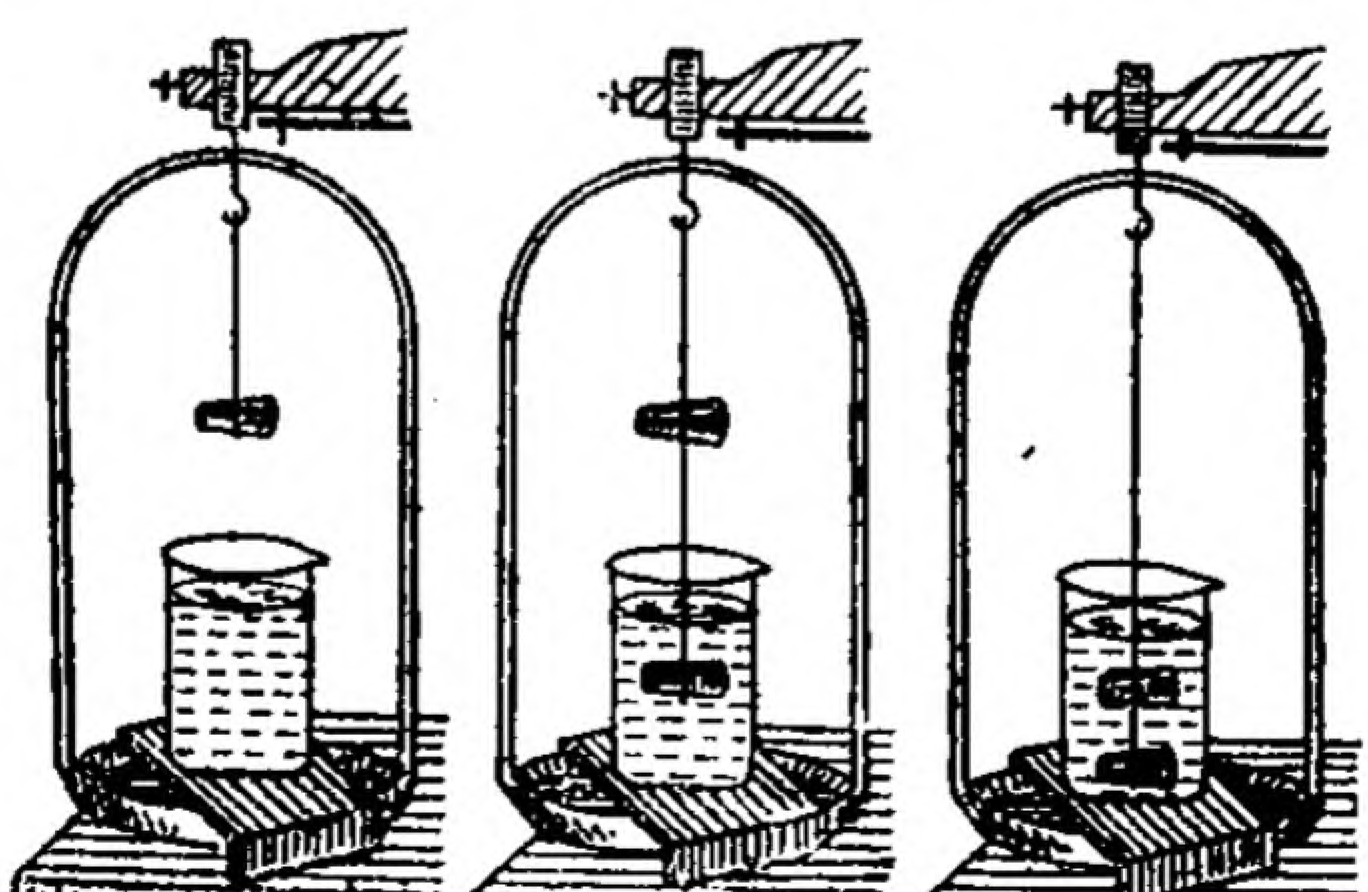


Fig. 34.

Tie a sinker (a glass stopper) with the same thread so that the sinker hangs well below it. Now place a wooden bridge across the pan of the balance and place a beaker $\frac{3}{4}$ full of water on it. See that the sinker is completely immersed and the solid is above the surface of water. Also see that there are no air bubbles sticking to the sinker. Weigh and record the weighing. Now tie the sinker and the piece of cork together and by suspending them from the hook of a balance weight them together. The difference between these two weighings will give us the weight of the water displaced by the piece of cork since the sinker remained immersed in the cases.

Record thus :

Temperature of water=

Weight of piece of cork in air $= W$

Weight of sinker in water and cork in air $= W_1$

Weight of sinker and cork both in water $= W_2$

Weight of water displaced by the cork $= W_1 - W_2$

Density of cork $= \dfrac{W}{W_1 - W_2} \times$ Density of water at that temperature.

Precautions.—1. The sinker should be completely immersed in water.

2. There should be no air bubbles sticking to the sinker or to the light solid when immersed in water.

3. Cut out all superfluous portions of the thread.

Exercise.—Find out the density of wax by applying the principle of Archimedes.

Temperature Correction.—Loss of weight of the solid in liquid=wt. of the volume of the liquid displaced=V c. cs× density of liquid.

$\therefore$ Volume of the body in c. cs. $= \dfrac{\text{Loss in weight}}{\text{Density of the liquid}}$

Hence density of the body $= \dfrac{\text{Weight of the body}}{\text{Volume of the body}}$

$= \dfrac{\text{Weight of the body}}{\text{Loss in weight}} \times \text{Density of the liquid.}$

NOTE.—For finding out the densities of solids and liquids by the application of principle of Lever see Chapter XI.

The Specific Gravity Bottle.—This is a bottle constructed so as to contain a definite volume of a liquid. In the common form this bottle is like a small flask with a slightly conical neck having a carefully fitted stopper which has a hole bored in it. The bottle is filled completely and when the stopper is inserted the excess of the liquid escapes through the hole and can be wiped away.

Fig. 35.

Experiment 18. **To determine the specific gravity of a liquid by using the specific gravity bottle.**

Apparatus.—Specific gravity bottle, kerosene oil, thermometer, duster, etc., arrangement for blowing hot air.

Method. The first thing to do is to clean and dry the specific gravity bottle thoroughly. Wash the bottle first with nitric acid and then with caustic potash so as to remove the grease, if any. Now wash with water and rinse it with a litttle alcohol. Then blow hot air into the bottle. This can be conveniently done as follows :—

Take a metal tube and fix it in a wooden support. At one end of the tube attach a foot bellows and at another connect a jet drawn glass tube. Heat the metallic tube by placing Bunsen flame underneath it and blow the air in from the foot bellows. Hot air will be found to come out from the glass tube. Pass this air through the bottle for some time; it will be perfectly dry. Cool and weigh the bottle now. Fill the bottle with so much of the liquid that on inserting the stopper a little of it should come through the hole in the stopper. This excess of the liquid should be dried by the blotting paper and the outside of the bottle should be cleaned thoroughly by a duster. Do not hold the bottle for a longer period than is necessary because the warmth of the hand will cause the liquid to overflow. Weigh the bottle when it is so filled. The difference between the two weighings gives the weight of the liquid having a volume equal to that of the bottle at the room temperature. Empty the bottle and dry it and fill it with water. Clean as before and weigh it. The difference between this weight of the empty bottle gives the weight of the water filling the

same volume as the other liquid. Let V c.cs. be the volume of the bottle.

Weight of V c.c. of the liquid filling the bottle
=Volume of the liquid × Density of the liquid.
Weight of V c.cs. of water filling the bottle
=Volume of water × Density of water at room temperature.

$$\frac{\text{Weight of V c.cs. of the liquid}}{\text{Weight of V c.cs. of water}}=\frac{\text{Density of the liquid}}{\text{Density of water}}$$

Hence density of liquid

$$=\frac{\text{Weight of V c.cs. of the liquid}}{\text{Weight of V c.cs. of water}}\times\text{Density of water.}$$

Record your observations thus :

Weight of the empty bottle $=W$

Weight of the bottle full of liquid $=W_1$

,, ,, ,, water $=W_2$

Density of the liquid at the room temperature

$$\frac{W_1-W}{W_2-W}\times\text{Density of water at that temperature.}$$

Precautions.—(1) Always interpose a dry duster or handkerchief between the bottle and the hand.

2. Do not press the stopper.
3. Wipe the bottle carefully dry.
4. There should be no air bubbles inside the bottle.
5. The bottle should be cleaned and dried thoroughly.
6. Fill the bottle to the brim so that on inserting the stopper a little of the liquid should come through the hole in the stopper.
7. Weigh each time accurately.

Experiment 19. **To determine the density of sand.**

Apparatus.—Sand, water, specific gravity bottle, balance, weights.

Method.—Clean and dry the bottle as given in the previous experiment and weigh it. Put in the bottle enough sand to fill $\frac{1}{3}$ to $\frac{1}{2}$ of the bottle and re-weigh. Put in a little water in the bottle and shake well to remove the air bubbles and finally fill it up to the brim and weigh. Empty out the contents from the bottle and fill it completely now with water and weigh it.

Record your observat'ons thus :

Weight of the empty bottle $= W_1$

Weight of the bottle + sand $= W_2$

Weight of the bottle + sand + water $= W_3$

Weight of the bottle filled with water $= W_4$

Temperature of water $= t^0$C

Weight of sand $= W_2 - W_1$

Weight of sand + the whole of bottle filled with water $= W_4 + W_2 - W_1$

Hence weight of water displaced by the solid $= W_4 + W_2 - W_1 - W_3$.

Specific gravity of sand $= \dfrac{W_2 - W_1}{W_4 + W_2 - W_1 - W_3} \times$ Density of water at room temperature.

Precautions.—The same as in the pervious experiment.

Exercise—Determine the density of a small quantity of mercury. *(P.U. 1939)*

Experiment. 20. **To determine the density of powdered salt.**

Apparatus.—Specific gravity bottle, balance, weights, common salt, kerosene oil, water.

Method.—Perform this experiment in a similar manner as the previous one except that we should take salt for sand and kerosene oil instead of water. If the density of kerosene oil is not given, then weigh the bottle last of all filled with water.

Record thus :

Weight of empty bottle $= W_1$

Weight of bottle + salt $= W_2$

Weight of salt $= W_2 - W_1$

Weight of bottle + salt + kerosene oil $= W_3$

Weight of bottle full of kerosene oil $=W_4$

Weight of bottle full of water only $=W_5$

Weight of kerosene oil filling the bottle $=W_4-W_1$

Weight of water filling the bottle $=W_5-W_1$

Weight of kerosene oil displaced by salt $=$ $W_4+W_2-W_1-W_3$

Sp. gravity of salt with respect to kerosene oil

$$=\frac{W_2-W_1}{W_4+W_2-W_1-W_3}.$$

Sp. gravity of kerosene oil

$$\text{Sp. gravity of salt}=\frac{W_2-W_1}{W_4+W_2-W_1-W_3}\times\frac{W_4-W_1}{W_5-W_1}\times\text{Density of water at the temperature.}$$

Precautions.—The same as in the previous experiment.

Exercise.—Find the density of crystals of sugar.

CHAPTER VII

APPLICATION OF ARCHIMEDES' PRINCIPLES TO FLOATING BODIES

Strength of Solutions.

Hydrometers.—The method of determining the specific gravity of a liquid with the help of a specific gravity bottle is a very good process. For commercial purposes we do not require a very accurate method, but on the other hand we require a simple method which should take very little time. For this purpose we use generally a special type of instruments called hydrometers. They all depend upon the principle of floatation. When a body floats in a liquid its weight is equal to the weight of the liquid displaced. Evidently either the hydrometer may have a constant weight, in which case it will sink to different depths in different liquid or its weight may be changed in order to sink it to the same level. Hence there are two types of hydrometers :—

(1) Hydrometers of constant weight but of variable immersion.

(2) Hydrometers of variable weight, but of constant immersion.

FIRST TYPE OF HYDROMETERS

The Common Hydrometer.—It consists of a (weighted) bulb of a definite weight provided with a vertical stem. When placed in a liquid of suitable density the hydrometer floats with part of the stem above the surface, the condition of equilibrium being that the weight of the instrument should be equal to the weight of the liquid displaced. The stem is graduated so as to indicate the specific gravity of the liquid.

Beaume's Hydrometer.—In the case of Beaume's hydrometer two different types are used, one for heavy liquids and the other for light liquids.

For heavy liquids $d=\dfrac{144{\cdot}3}{144{\cdot}3-\text{reading}}$.

For light liquids $d=\dfrac{144{\cdot}3}{144{\cdot}3+\text{reading}}$.

The Twaddel Hydrometer.—A number of these are arranged in a box and only one which can float in the liquid upto a graduation on the stem is used. The density is given by $\dfrac{5\times\text{reading}+1000}{1000}$.

It is used for heavy liquids only.

Lactometers, Salinometers, Urinometers are used for milk, salt solutions and urine. They are specially graduated to give directly the concentration of the solution concerned.

Experiment. 21. **To determine the density** (*a*) **of copper sulphate ($CuSO_4$) solution ;** (*b*) **of kerosene oil by** (*i*) **common hydrometer** (*ii*) **Beaume's hydrometer,** (*iii*) **Twaddel hydrometer.**

Apparatus.—Common hydrometer, Twaddel hydrometer, Beaume's hydrometer, $CuSO_4$ solution, kerosene oil, tall jars.

Method.—Put each of the liquids in turn in a tall cylinder and gently float the hydrometer. Note as accurately as you can the height to which the liquid rises on the graduated stem. Put some sand or cotton wool at the bottom of the jar so that if the hydrometer happens to touch the bottom the bulb may not break. Wipe and dry the instrument after each reading. Do not allow it to touch the sides and remove all air bubbles sticking to it. Take 3 independent readings. In the case of Beaume's hydrometer, "heavy" or "light" is printed (marked) on the stem. The "heavy" should be used grams of the salt we have to make the solution upto $\dfrac{100\times x}{20}$ for copper sulphate solution and that having "light" on the stem for oil. Twaddel hydrometer is to be used for $CuSO_4$ solution only. It is never used to find the specific gravity of a liquid lighter than water.

Note the temperature of the liquid.

Record as follows :—

Temperature of the liquid=

Solution used.	Common hydrometer.	Beaume's hydrometer.	Twaddel hydrometer.
$CuSO_4$	(1) Reading= (2) Density = (3) Density corrected for temp.=	(1) (2) (3)	(1) (2) (3)
Kerosene oil			

Precautions. 1. The height to which the liquid rises on the graduated stem should be noted very accurately.

2. Do not allow the hydrometer to touch the bottom, otherwise the bulb might break.

3. Wipe and dry the instrument after each reading.

4. Do not allow it to touch the sides and remove all air bubbles sticking to it.

5. Avoid parallax error in taking a reading.

6. In case of liquids which stick to the surface of the hydrometer, reading is taken at the lower meniscus, *i.e.*, the reading up to which the instrument sinks.

Experiment 22. **To prepare a 20 per cent. solution of common salt.**

Apparatus.—A balance, watch glass, etc.

Method.—Weigh out some convenient amount of salt (say x grams) in a watch glass and put it in a graduated cylinder. To calculate the amount of water to be added we proceed as follows :—

If the salt in the cylinder had been 20 gms. we should have added water to make the solution upto 100 c.cs. mark. For $x=5x$ c.cs. mark. This would be 20 per cent. solution of the salt.

Shake the salt in the cylinder by a glass rod so that a homogeneous mixture is obtained.

Precautions. 1.—The watch glass must be carefully washed with water so as to remove all traces of salt from it.

2. Shake the water in the cylinder well to make a homogeneous mixture.

SECOND TYPE OF HYDROMETER

Nicholson's Hydrometer.—It is a hydrometer of constant (definite volume) immersion but variable mass. It is immersed up to a fixed mark in all liquids, weights being added to it as needed. It consists of a cylindrical float usually with conical ends. Above this rises a different brass stem carrying a small scale pan while underneath the float is fixed a small basket. The basket is usually loaded with lead so that the instrument floats vertically with part of the upper cone projecting out of water. A perforated cup is sometimes fitted so that the basket can be covered at will.

Experiment 23(a) **To determine the specific gravity of solid** *(b)* **liquid by Nicholson's hydrometer.**

Apparatus.—Weight box, tall cylinder, $CuSO_4$ solution, a piece of glass.

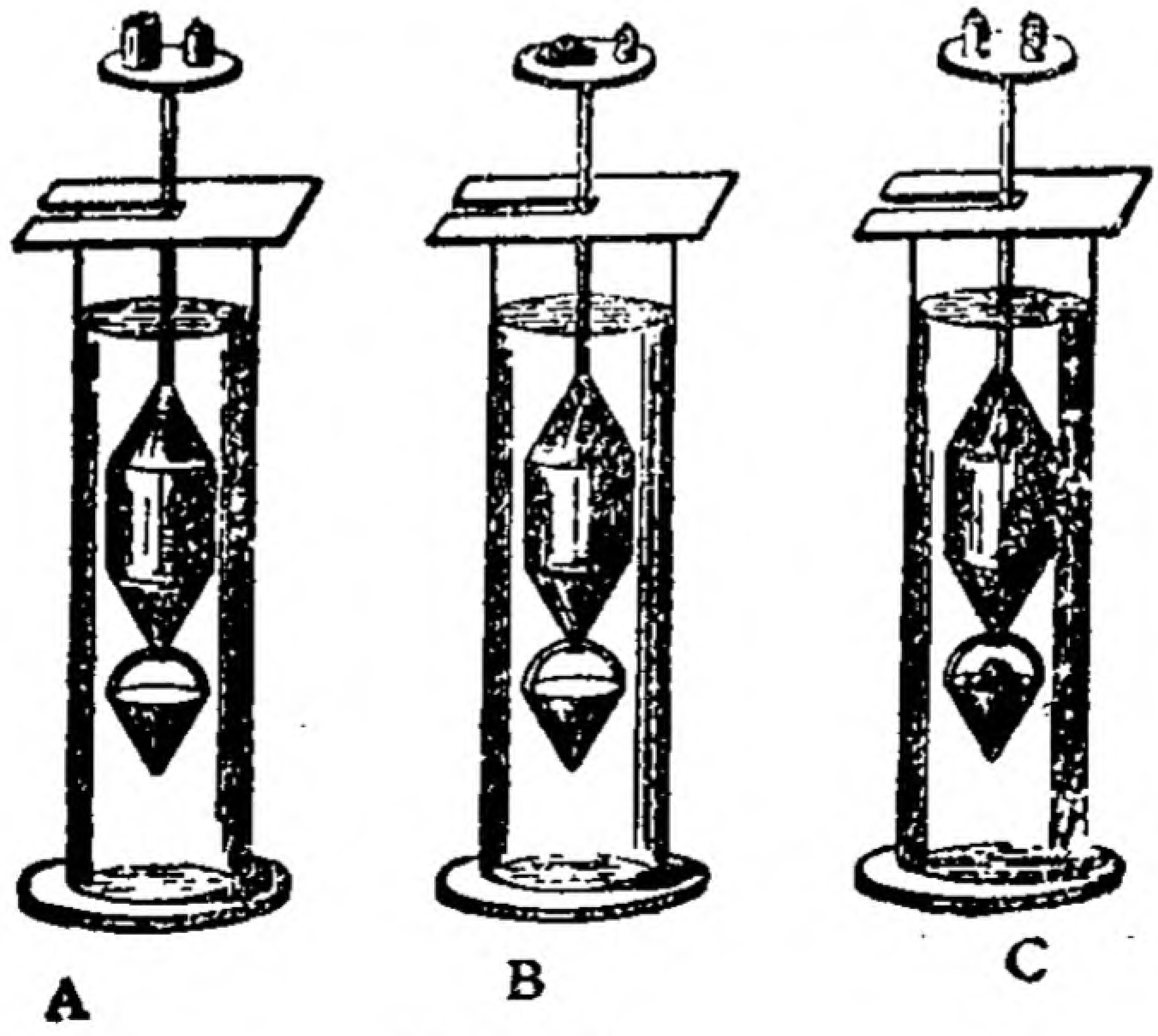


Fig. 36.

Method.—*(a)* Float the hydrometer in water in a tall cylinder and place weights on the scale-pan till the hydro-

meter is immersed as far as the mark filed on the upper brass stem. It is advisable to place a slotted sheet of metal or cardboard across the top of the jar or cylinder containing water, the stem supporting the scale-pan being in the slot which should be made wide enough for the stem to move quite freely up or down. This sheet of metal prevents the hydrometer from sinking into water if too heavily loaded, thereby avoiding wetting the scale-pan and the weights. It also prevents the hydrometer from coming into contact with the sides of the jar.

Let the weight required to sink the hydrometer up to the mark be $=W_0$ gms.

Next place the solid whose specific gravity is required on the scale-pan and add weights till it is again immersed upto the same mark. Let this be W_1 then the weight of body in air is W_0-W_1.

The body is now placed in the basket and the hydrometer is sunk again to the mark by placing weight W_2 in the scale pan. Therefore the upthrust $=W_2-W_1=$ weight of water having a volume equal to that of the solid.

$$\text{Sp. gravity}=\frac{W_0-W_1}{W_2-W_1}.$$

Precaution. It is important to remove all the air bubbles sticking to the hydrometer.

(*b*) Float the hydrometer in water and add weights to scale pan till it sinks to the mark. Let this be W_0. Next float it in the liquid whose specific gravity is required and add weights to sink it to the same mark again. Let it be W_1. Weigh the hydrometer. If its weight is W then $W+W_0$ is the weight of the water displaced when the hydrometer is sunk to the mark in water and $W+W_1$ is the weight of the liquid displaced when sunk to the mark in the liquid. But the volume displaced is the same in each case. Hence specific gravity of the liquid $=\dfrac{W+W_1}{W+W_0}$.

CHAPTER VIII

PRESSURE IN LIQUIDS, RELATIVE DENSITY

(1) The pressure exerted by a column of the liquid is independent of the shape of the containing vessel ; the pressure then depends solely on the vertical height of the column and its density. The pressure in dynes per sq. cm. exerted by a column of the liquid of height h cm. and density D gms. per c. c. is equal to hDg, g being acceleration due to gravity.

(2) The pressure at two points in a horizontal plane is the same provided they are both situated in the same liquid.

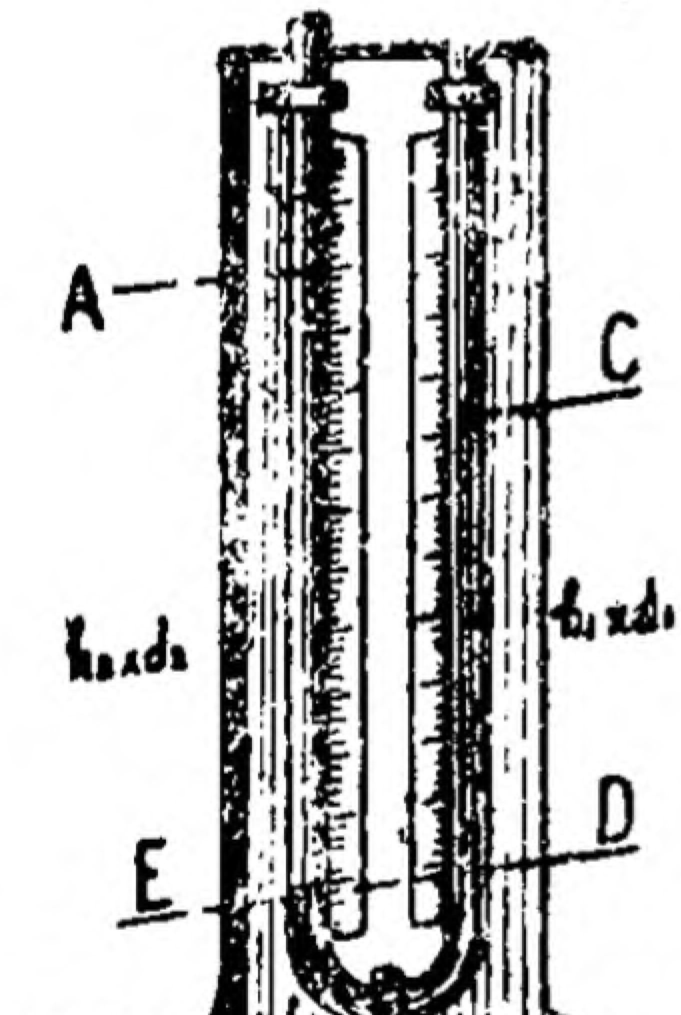


Fig. 37.

These are the principles which underlie the method for comparing the densities of liquids by balancing columns.

Suppose we have a U-tube as shown in the diagram. Pour water in this tube so that $\frac{1}{2}$ of each limb is filled. Next pour kerosene oil through one of the limbs of the tube. Water will be depressed on that side and will rise in the other limb. The amount of the kerosene oil must be so much that water remains in both the limbs.

Let E be the surface of the two liquids. E and D are at the same level hence the pressure at these points which are in the same horizontal is equal. Let the height above the separation at D be h_1 and above E be h_2 and let the densities be d_1 and d_2 respectively. The pressure at the point D will be $h_1\ d_1$ gm. per c.c. Similarly the pressure at E will be $h_2\ d_2$ gm. per c.c. But as has been stated these must be equal.

Hence $h_1d_1=h_2d_2$.

or $$\frac{d_1}{d_2}=\frac{h_2}{h_1}.$$

i.e., densities are inversely proportional to heights. If d_2 be the density of water the ratio gives the specific gravity of the liquid.

NOTE.—(1) We have not taken into consideration the pressure due to the atmosphere since it is common on both sides and hence it does not affect the heights of the liquid columns.

(2) If two liquids mix a third liquid usually mercury is used to keep the columns separate, the mercury being at the same level at each side of the bend. The columns are measured above the level of mercury. As a slight difference in the mercury level will cause a great error (a diff. of 1 mm. of mercury will cause difference of 1·36 cm. of water) this method, therefore, is not ordinarily used.

The Y-tube or inverted U tube, also known as **Hare's apparatus** can be used for determining the densities of liquid which mix or chemically react on one another. It is made up of two straight pieces of glass tubing of equal length and joined together by a three way tube. The Y tube thus joined can be set up vertically in an inverted position. The open ends of the glass tubes are placed in beakers, one containing water and the other the given liquid. A pinch cock is attached to the open end of the three way tube by which it may be closed tight. By sucking in the air at the open end the liquids are drawn up the tubes to different heights, the less dense being drawn to a greater height. Since the pressure in the tube decreases the atmospheric pressure pushes the liquids in the arms and the less dense is pushed to a greater height. The

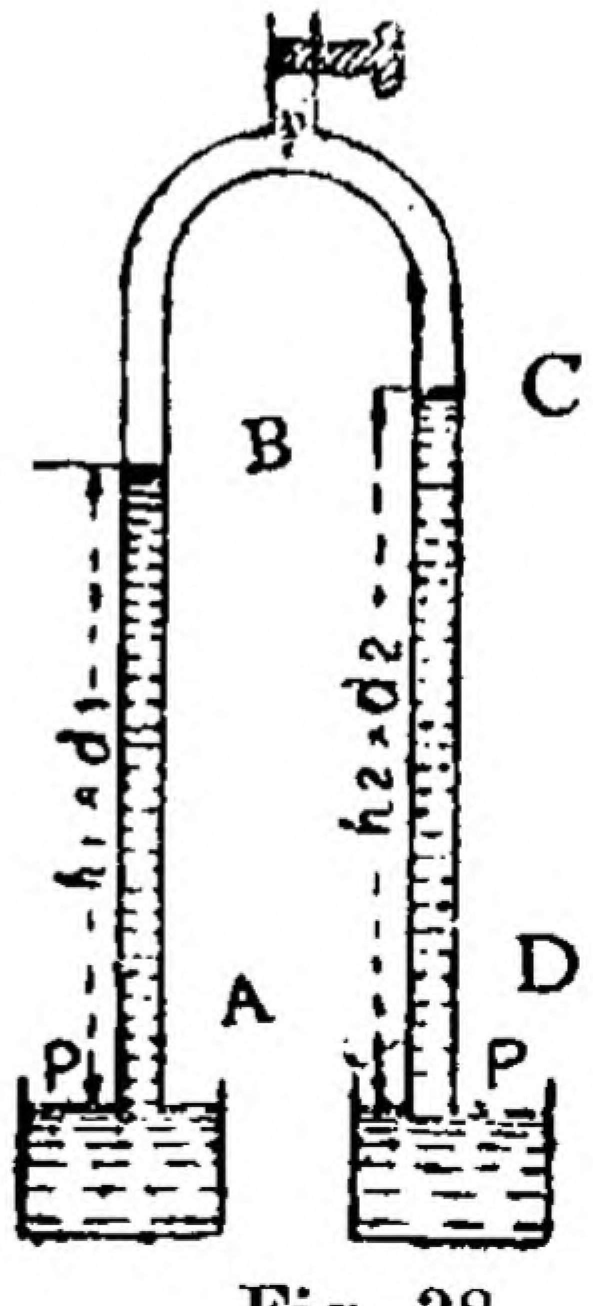


Fig. 38.

pressure at A and D is the same and also the pressure at B and C is the same being the atmospheric pressure. Hence the pressure due to the column A B must be equal to the pressure due to the column C D. If d_1 and d_2 be the densities of the two liquids, we have

$$h_1 d_1 = h_2 d_2$$

$$\text{or } \frac{h_2}{h_1} = \frac{d_1}{d_2}.$$

The W or double U-tube.—It consists of two U tubes connected together by a rubber tubing. The W tube so formed is set vertically and water is poured in from one end and the given liquid from the other. The level of each liquid will be different in the open and closed arms. The pressure of the air enclosed in between the two liquids will be greater than that of the atmospheric pressure because it is compressed.

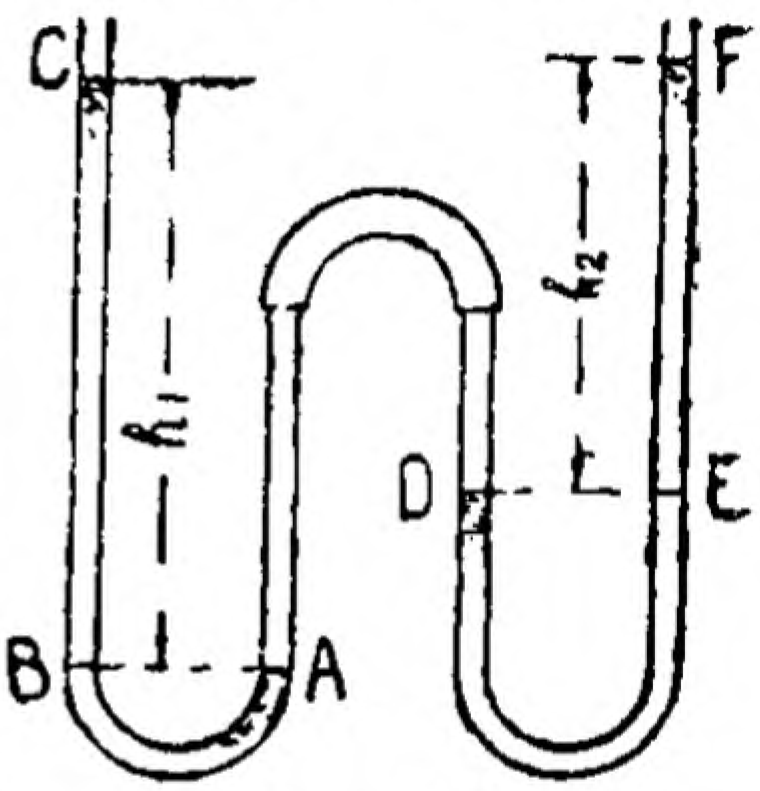


Fig. 39.

The two liquid surfaces in the closed arms are both under this compressed pressure. Let us call this compressed pressure P′. In the open arms they are under the atmospheric pressure. The excess of pressure of air in the closed part over that of the atmospheric pressure is evidently equal to $P' - P = h_1 d_1$ in one limb and $P' - P = h_2 d_2$ in the other limb.

But this difference of pressure is the same in both the limbs, hence

$$h_1 d_1 = h_2 d_2.$$

$$\therefore \frac{h_2}{h_1} = \frac{d_1}{d_2}.$$

Experiment 24.—**To determine the density of oil by means of a U-tube.**

Apparatus.—U-tube, water, oil, metre rod, set squares.

Method.—Clean and dry the tube and fix it vertically (use a plumb line). By using a small funnel fill half the

limb with water. Gently pour oil through a limb so that the junction may be 4 or 5 cms. above the bend of the U tube. Hold a metre rod vertically close to and parallel to the tube. Read the position of the junction of the two liquids by means of set squares.

Next read the free surfaces of oil and water. Empty the tube, rinse it with petrol and dry again. Refill and determine the density a second time.

Repeat the same operation a third time.

Record thus :—

Temperature of the room=

No. of observations	Height of the junction	Height of oil surface	Height of water surface	Length of oil column	Length of water column	Density of oil

Precautions :—1. The small bubbles from the inside of the glass tube should be removed.

2. The surface of separation of the two liquids should be well marked and not distorted.

3. Readings should be taken with a set-square.

4. Eyes should be kept in level with the liquid surface.

5. Tubes and scale should be kept vertical.

Experiment 25.—**To determine the density of copper sulphate ($CuSO_4$) solution by a W-tube.**

Apparatus.—W-tube, metre rod, clamps.

Method. Clean the tube by rinsing it with petrol and dry it. Clamp it in a vertical position, Pour water in one limb till the two adjacent limbs are half filled. Then pour the copper sulphate ($CuSO_4$) solution through the other limb so that it also is in the two limbs on the other side a little above the bend. Do not pour so much of the liquids that they may mix. Pour more of the liquid till the two columns occupy suitable lengths of the tube. Read height of the free surfaces of the liquids by means of set-squares and repeat the experiment with different heights.

Record thus :—

Temperature of water=

Density of water=

No. of observation.	Water Column. h_1			Oil column. h_2			Density $\frac{h_1}{}$	Mean Density.
	Reading of one limb.	Reading of the other limb.	Height of water column	Reading gf one limb.	Reading of the other limb.	Height of oil column.		

Density corrected for temperature =

Precautions :—Same as in the previous experiment.

Experiment 26.—**To determine the density of oil with inverted Y- tube (Hare's apparatus).**

Apparatus.—Inverted Y-tube, water, turpentine oil, two beakers, metre rod.

Method.—Put the two ends of the tubes into the two beakers so that they are nearly at the end and clamp the tube vertically. Suck in air from the glass tube till the

lighter of the two liquids has risen nearly to the top of the corresponding column close to the pinch cock. Measure the height of the two liquid columns above the level of the liquids in the corresponding beakers. This can be done as follows :- Hold two knitting needles in clamps with the help of corks (or the same needle turn by turn) so that the lower ends touch the free surfaces of the liquids in the beakers. Place a metre rod vertically close to the two limbs and by means of a set square take the readings opposite to the top ends of the needles and of the liquid columns in the tubes. The difference will give the columns of liquids in the tube above the upper ends of the needles. Measure the length of each needle and add it to the corresponding column of the liquid (obtained above), the sum in each case gives the length of the liquid column of that side. Take three observations.

Record thus :—
Temperature of water =
Temperature of liquid =

No. of observation.	Water Column. h_1				Oil Column. h_2				$\frac{h_1}{h_2}$
	Length of the needle.	Upper end of the needle.	Top of water column.	Length of water column.	Length of the needle.	Upper end of the needle.	Top of oil column.	Length of oil column.	

Mean=
Corrected density=

CHAPTER IX

ATMOSPHERIC PRESSURE—BOYLE'S LAW

Surrounding the earth in every latitude, over land and sea is a gaseous envelope which is spoken of as the air or atmosphere. The atmosphere exerts a pressure or force per unit area similar to that of liquids which we have already dealt with. This force per unit area or pressure can be balanced by a column of any liquid, but since mercury is the heaviest of the liquids known, a column of mercury can be easily managed for demonstration. Procure a long tube (which may be closed at one end) of about 32 inches and connect a short piece of India-rubber tubing to its open end. Bind the free end of the rubber tubing to a glass tube about 6 inches long and open at both ends. Keep the long tube with its closed end downwards and pour mercury into it (being careful to remove all air bubbles) until the liquid reaches the short tube. Then fix the arrangement upright. The mercury in the long tube will be seen to fall so as to leave a space of a few inches between it and the closed end.

The distance between the top of mercury column in the closed tube and the surface of that in the open tube will be found to be about thirty inches. It is clear that there is a column of mercury supported by some means which is not at first apparent or else the mercury would sink to the same level in the long and the short tubes, for we know that liquids find their own level. If a hole were made in the closed end of the long tube this would happen immediately. There will be no difficulty from what has been said already in understanding that the column of mercury is kept in position by the weight of the atmosphere pressing upon the surface of mercury in the short open tube. The weight of this column of mercury and the weight of column of atmosphere with the same sectional area is exactly the same, both being measured from the level of the mercury, in the short stem of the apparatus and the mercury column

to its upper limit in the long tube, the air to its upper limit which is at a great distance from the surface of the earth. When for any reason the weight of the atmosphere becomes greater, the mercury is pushed higher to preserve the balance. When it becomes less, then similarly the amount of mercury which can be supported is less and so the height of column of mercury is diminished. An arrangement like that described constitutes a barometer.

If an area of cross-section of both the limbs be regarded as one sq. cm. the mercury in the column will have a volume 76 c.cs. and we may say that the weight of 76 c.cs. of mercury=Atmospheric pressure per sq. cm.

If we want to find out the weight of 76 cm. of mercury we shall have to multiply it by its density (13·6) ; and if it is to be expressed in absolute units then we must multiply by g, or in general if the height be h cm. of mercury and d be its density then the atmospheric pressure in absolute units is hdg dynes per sq. cm. But the height of mercury is affected by temperature ; we must therefore apply the temperature correction.

Temperature correction.—Since the density of mercury changes with the temperature, a column of mercury, say 30 inches high, on a hot day does not represent the same pressure as a column of the same height on a cold day. Hence it is necessary to reduce all barometric readings to some standard temperature usually 0°C.

Suppose the temperature to be t°C, then if y be the co-efficient of expansion of mercury, the reduced height h_0 is less than the actual height h in the ratio of $1+yt$. The observed height should therefore be divided by $1+yt$.

If the height be measured by means of a metallic scale, a further correction is necessary on account of the change of length of the scale. Suppose this to be correct at 0°C the effect of rise of temperature is evidently to make the divisions on the scale too long and therefore the number of divisions occupied by the column of mercury is less than it should be in the ratio of 1 to $1+zt$ where z is

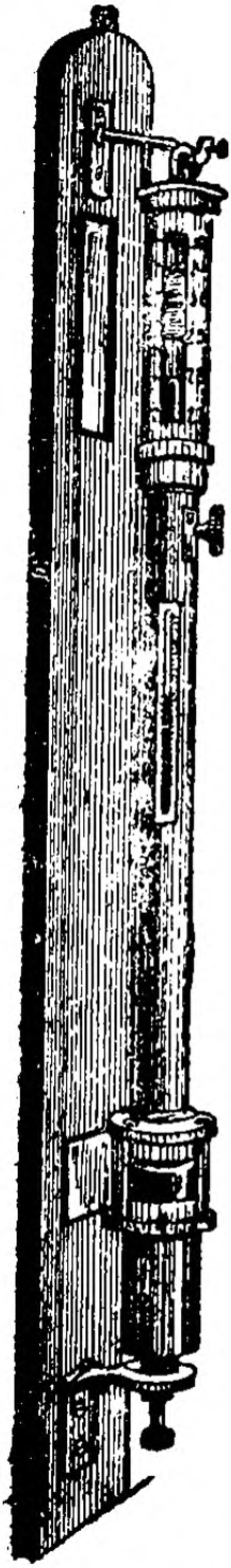


Fig. 40.

the co-efficient of linear expansion of the material of which the scale is made. The observed height h must be multiplied by $1+zt$. Finally the reduced height $h_0 = h\,\dfrac{1+zt}{1+yt}$ or what is very nearly the same $h_0=h[1+(z-y)t]$. The value of z for brass is $\cdot000018078$ and y is $\cdot00018018$, whence

$$h_0=h[1-\cdot0001614t]$$

when the scale is made of brass and is correct at 0°C.

Fortin's Barometer (Fig. 40) :—In the barometer we have considered that whenever the pressure will decrease or increase the mercury will be forced into or out of the smaller tube. This will not let us measure the height of the barometer from a fixed scale, as the level from which we are to make our measurements will always be changing. In a Fortin's Barometer the tube dips in a cistern with a leather bottom. The bottom can be raised or lowered by a screw so as to bring the surface of mercury always to the zero of the fixed scale. This zero coincides with the top of the ivory peg just above the mercury in the cistern. When the mercury surface just touches the top of this peg, the reading of this surface is zero and the reading of the top surface on the scale gives the barometric height at once.

Experiment 27. **To read the Fortin's Barometer and to reduce its readings to 0°C.**

Apparatus.—Fortin's Barometer.

Method.—Before setting the Fortin's Barometer to take readings, note the temperature of the air on the thermometer attached to the barometer. Gently turn the lower screw so that the ivory peg is clearly visible against the milk-white background provided. Now turn the adjusting

screw up till the peg touches the mercury surface. If the mercury surface is white see that the tip and the image of the peg just touch each other. Near the top in the copper tube surrounding the glass tube there is a slot in which slides up and down a vernier. At the back also there is a slot in which a brass plate connected with the vernier slides. The lower edge of the back plate is just at the same level as the zero of the vernier. To take a reading, the vernier is moved till the lower edge of the vernier, the lower edge of the back plate and the top of the surface of mercury and the eye are all at the same level *By means of a plumb line see that the barometer is vertical.* Then note (1) the nearest inch or centimetre mark below the zero of the vernier ; (2) the number of complete divisions between the nearest inch or centimetre mark and the zero of the vernier ; (3) the number of the vernier division which coincides with a division on the scale. Take three or four independent readings.

Applying the temperature correction :

$h_0 = h_t\ (1 - \cdot 00016t)$.

For vernier reading, consult this book.

Precautions :—1. The barometer must be vertical.

2. The ivory peg should just touch the surface of mercury.

3. While taking readings see that the lower edge of copper slot shall be like a tangent to curved (upper) surface of mercury.

Exercise. (1) Measure the pressure of gas supply.

[*Hint.* Pressure of gas = atmospheric pressure + pressure due to oil column equal to difference of two levels of mercury contained in a U tube. But this oil column should be converted into corresponding mercury column, remembering that $h_1 d_1 = h_2 d_2$ where h_1 is the height of oil column and d_1 its density and h_2 the height of mercury column and d_2 its density.]

Exercise (2) Given a U-tube, scale, oil, and mercurial barometer, find the height of the oil barometer.

Exercise (3) Given the atmospheric pressure and density of glycerine, calculate the height of glycerine barometer.

Boyle's Law.—The volume of a given mass of gas kept at constant temperature is inversely proportional to the pressure; or the product of the pressure and the volume of gas at constant temperature is constant.

Boyle's Law apparatus (Fig. 41) :—It consists of a glass tube 25 cm. long and ½ cm. in diameter sealed at one end and open at the other. The open end is drawn out and attached to a rubber tubing. The other end of this tubing is attached to a second piece of glass tubing about 1 cm. in diameter. The first tube is clamped to a vertical board so that it is also vertical while the second tube is attached to a slide which moves up and down a vertical rod and can be clamped in any required position. The lower parts of the glass tube and the rubber tubing is filled with mercury and thus some dry air remains confined in the closed end and mercury surface of the first tube. A metre rod fixed to the board enables the level of mercury in the two tubes to be read. Adjust so much of the mercury that when the level is equal in both the tubes it should stand half way up the closed tube.

600

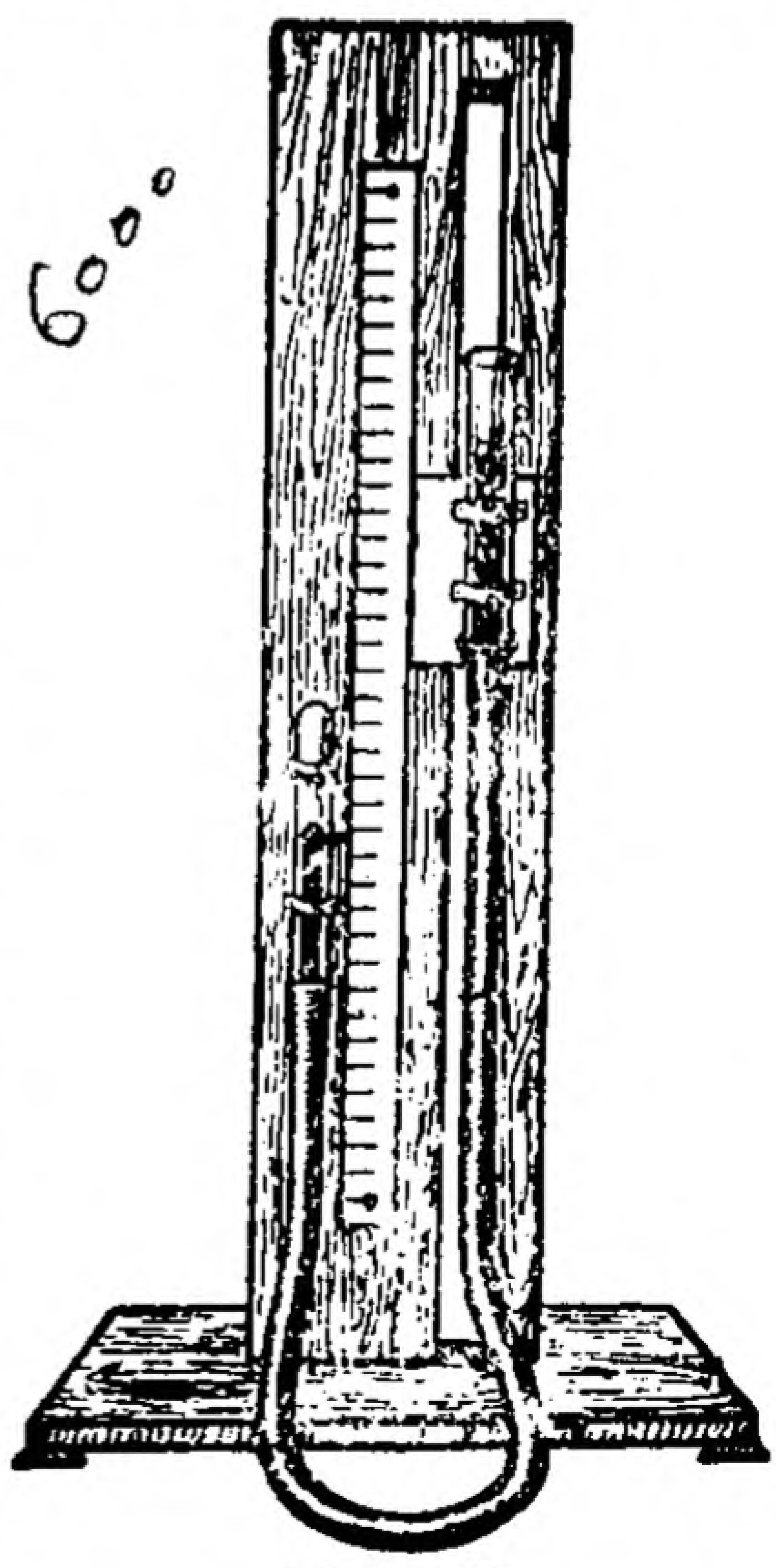


Fig. 41

Experiment 28. **To verify Boyle's Law.**

Apparatus.—Boyle's Law apparatus, set squares, barometer, thermometer, plumb line.

Method.—Set the Boyle's Law apparatus vertical by means of a plumb line and read the thermometer and barometer to get the temperature and atmospheric pressure. Adjust the position of the movable tube on the scale so that the level of mercury in the open and closed tubes is nearly the same. This can be done by putting one edge of one set-square in contact with the board and the other edge perpendi-

cular to the plane of the board. Put the other set-square in contact with the first set-square and along the scale. Keep its horizontal edge at the same level as that of the mercury surface to be read.

Read the meniscus by means of a set-square. This can be conveniently done by placing a set-square such that its one edge is vertical and the other edge horizontal. Place the horizontal edge tangential to the surface of the mercury.

Take readings by means of set-squares. Read on the vertical scale the height of mercury in the inner side of the closed tube and also the mercury level in the open end of the tube. Read the length of the spherical part (inside) and multiply it by $\frac{2}{3}$. Add this to the reading of the level of mercury in the closed tube where the spherical portion commences. This will give us the true reading of the closed end. Raise the open end by a few centimetres and again read the level of mercury in the two tubes. The volume of air will become less and less, by raising the open tube to different heights and take from five to six readings. Now bring the open tube to the same position from which you started and lower it step by step taking reading at every place as before.

Take from two to three readings. Read the barometer and thermometer again. Calculate the total pressure P, *i.e.*, barometer pressure plus or minus the difference of level in mercury surfaces in each case and also the length of the air column (V) in the closed tube for each pressure. Find the product of P and V in each case.

Record thus :

Temperature of air

(1) in the beginning=

(2) at the end=

Reading of Barometer (P) (1)...(2)...Mean=

Reading of the closed end of the tube (upto the place where the spherical portion commences $\times \frac{2}{3}$rd. of the length of the spherical part)=

No. of observation	Level of Hg. in open end	Level of Hg. in closed end	Diff. of level in cms. (h)	Total pressure P $P \pm h$	Volume or effective length of air column	PV	$\frac{1}{V}$

Plot curves between P and $\frac{1}{V}$ and between P and V.

The former will be a straight line passing through the origin.

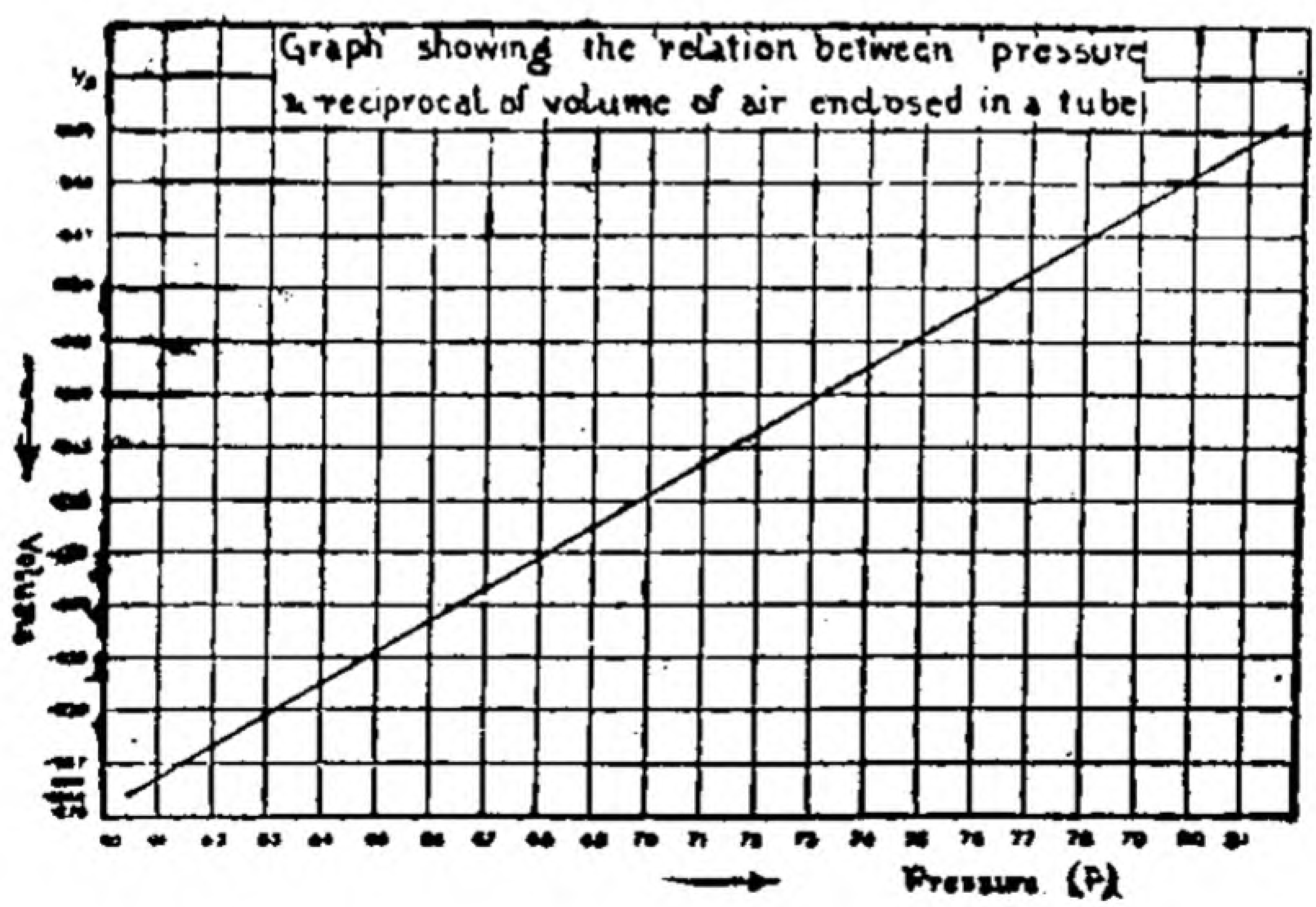


Fig. 42

Fig. 42 shows a curve for P and $\frac{1}{V}$ that has been drawn from readings taken by a student in the laboratory.

Figure 43 shows the curve between P and V.

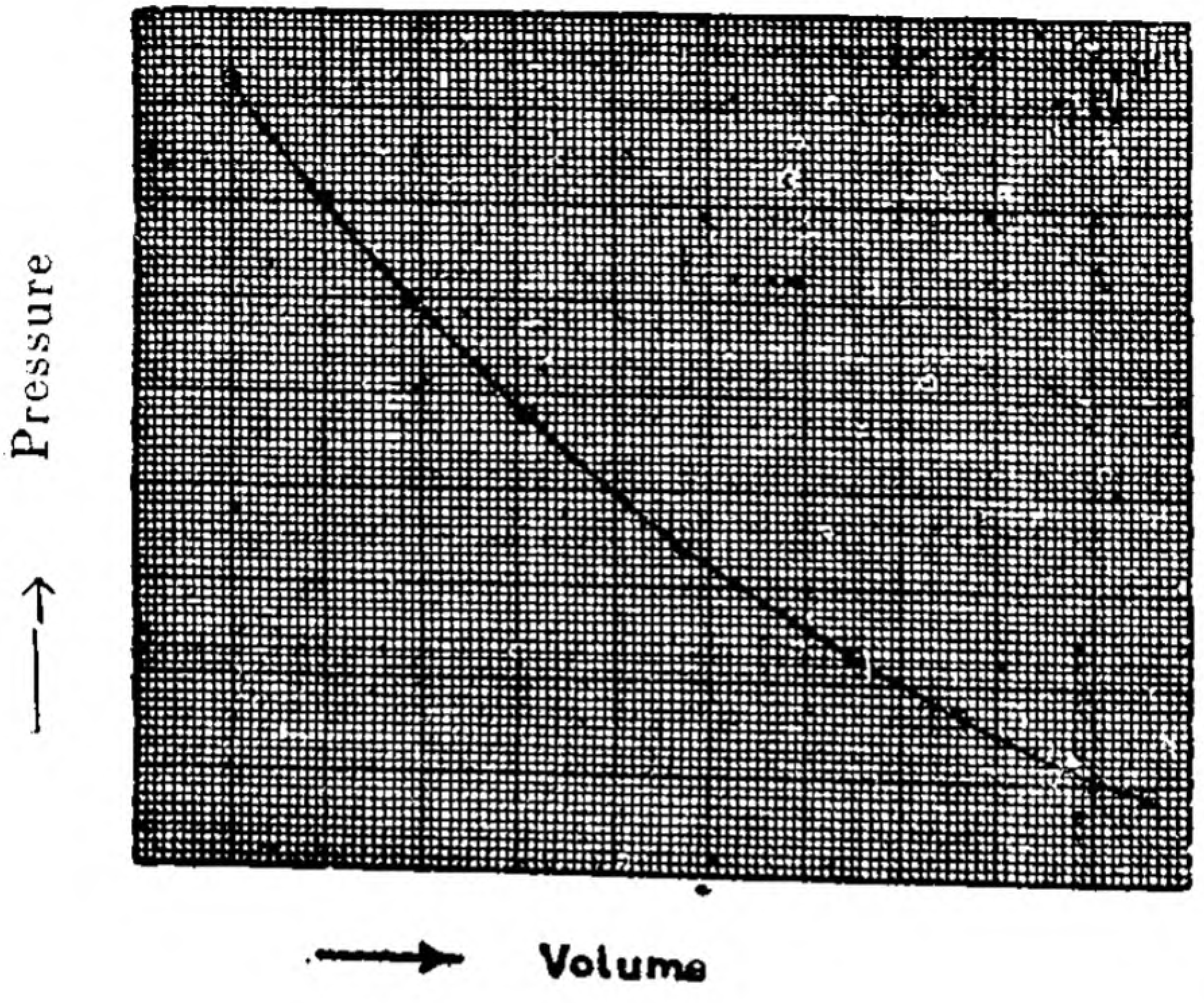


Fig. 43.

Precautions :—1. Set the Boyle's Law apparatus vertical by means of the base screws and the plumb line.

2. See that the mercury is clean and does not stick to the sides of the tubes.

3. Take readings with the help of a set-square, keeping its one edge vertical and along the scale and its horizontal edge should be like a tangent to the upper surface of meniscus of mercury.

4. Take two-thirds of the length of the spherical part and add this to the reading of the level of the closed tube.

5. Parallax error is to be avoided.

6. Before commencing the experiment test that the apparatus is not leaky. For this purpose, raise the open tube.

Exercise 1. Determine atmospheric pressure when you are given the apparatus for verifying Boyle's law.

[*Hint.* Let the difference in levels of mercury in the two tubes be equal to h. Plot a graph between h and $\frac{1}{V}$ and find the point where the graph cuts the axis of h. The atmospheric pressure is obtained by finding the intercept on the axis of h between zero and the point where the graph cuts it.

Or

Let the atmospheric pressure be equal to P. Raise the reservoir so as to compress air in the closed tube. Let h be the difference of two levels of mercury in the two tubes and V the volume of air. Again raise the reservoir and find h_1, the difference of two levels of mercury in the two tubes and let V_1 be the volume of air column.

$$(P+h)V=(P+h_1)V_1$$

$$PV+hV=PV_1+h_1V_1$$

$$P(V-V_1)=h_1V_1-hV$$

$$P=\frac{h_1V_1-hV}{V-V_1}.$$

Elasticity

When a force of any kind acts on a body, the body is deformed to a greater or lesser extent. The deformation will, in general, disappear if the forces cease to act. The restoration takes place as a result of that property of the body itself which is called *Elasticity.*

The law connecting the forces acting and the deformation produced is known as Hook's Law. This may be stated as 'tension is proportional to extension or stress is proportional to strain.' Hook's Law is only true up to a certain point if the stress acting on the body exceeds a certain value, the body will not return to its original dimensions when the strees is removed. The largest deformation which does not have a permanent distortion is called the Elastic Limit of the subtance. Up to the elastic limit, Hook's Law holds good to a close degree of approximation.

Definition of Stress and Strain. *Stress* may be defined as the force exerted per unit area. *Strain* is the force exerted per unit dimension.

Experiment. 29. **To verify Hook's Law.**

Apparatus.—A spiral sping, weight box, a pan, stand with a scale fixed on it, etc.

Method.—Make a loop at one end of the spiral spring and hang it by a nail on the metre rod fixed on a stand just behind the spring in a vertical position for taking the reading of the pointer. Suspend a pan from the free end of the spring and fix the needle just a little above the pan as shown in Fig. 44.

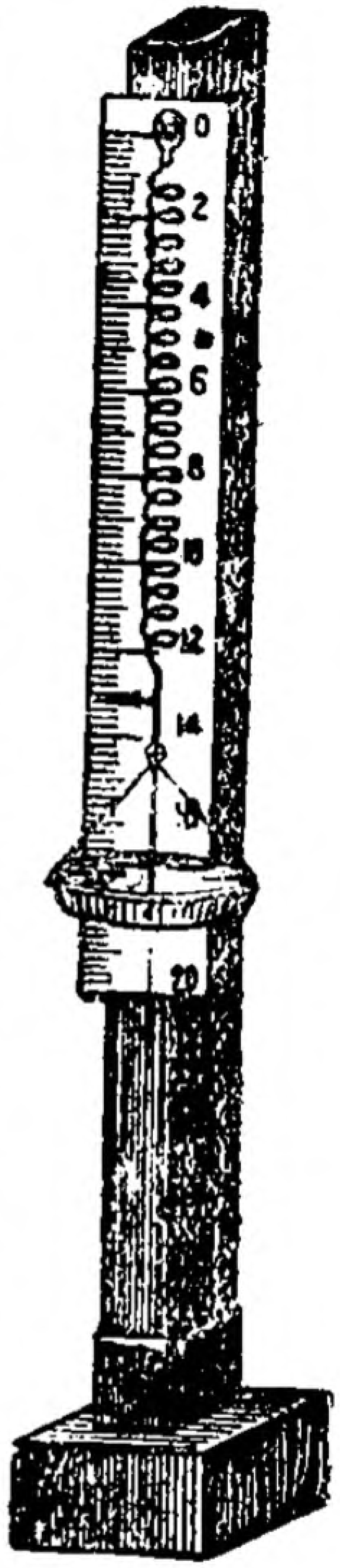


Fig. 44.

See that the spring is tightly stretched; if not, put some weights in the pan so that it may be stretched. Also be sure that the end of the needle does not touch the scale but simply moves parallel to the scale. Take the zero reading of the pointer. Add weights from 5 to 10 grams each time and go on taking the readings. Unload the pan in the same manner and go on observing the position of the pointer.

Record your observations thus:—

Load in pan (stress)	Reading of needle on the scale	Extension (strain)	$\frac{\text{Stress}}{\text{Strain}}$

Exercise :—Plot a curve between stress and strain.

Precautions.—1. Do not take the readings when the weights are added, but take readings after about a minute.

2. The distance from the point of support can be better measured if a record needle is attached to the spiral spring near the top and the distance between the two needles is the required length each time. This increase in the length of the spring can be easily calculated.

3. Do not add so much weight as to extend it beyond the elastic limit.

Young's Modulus

In the case of wires when elongation in length is only considered the strain is measured by the increase per unit length and ratio $\dfrac{\text{stress}}{\text{strain}}$ is called "Young's Modulus". Let L cms. be the length of a wire of radius r cms. and let it be stretched by a force of M gms. weight which brings about an increase of l cms. in length of the wire, then

$$\text{stress} = \frac{\text{Force}}{\text{Area}} = \frac{Mg}{\pi r^2}$$

$$\text{strain} = \frac{l}{L}$$

$$\therefore \text{ Young's modulus} = \frac{Mg}{\pi r^2} \div \frac{l}{L}$$

Experiment 30 :—**To determine Young's Modulus for a material in the form of a wire.**

Method.—Keep the wire A straight by suspending a hanger H. By means of a screw-gauge measure the diameter of the wire at different points along the length of the wire at each point the measurement must be made along two mutually perpendicular diameters. Measure the length of the wire from the point of support to the zero of vernier. Note the reading on the vernier and the scale. Now add a kilogram weight and again note the reading. The difference between the two readings gives the elongation produced. [illegible] ght from the scale pan and take the reading.

If this reading is very nearly the same as the previous one repeat the process gradually increasing the weight by steps of 1 kilogram to a maximum within the elastic limit.

If the readings on removing the weights are different from those on adding the weights they may be rejected. This happens due to kinks in the wire. In such a case sufficient weights may be added until a series of concordant readings are obtained. Next remove the weights one by one, in the same order in which they were added and take the readings as before.

Enter your observations thus:—

Length of the wire=..........................cms.

Diameter of the wire at six different points

(*i*) (*ii*) (*iii*) (*iv*) (*v*) (*vi*)

Mean diameter =........................cms.

Load in K. grams	Reading		Mean reading	Elongation for an increase of 3 K. gram
	Load increasing	Load decreasing		

Mean extension for 3 k. gms.=..................cms.

Extension for 1 kilogram or 1000 gms.=......cms

$$\gamma=\frac{\text{Stress}}{\text{Strain}}= \text{.....dynes/cm.}^2$$

Precautions :—1. The elastic limit of the wire must be tested beforehand.

2. The diameter should be measured very accurately as the square of the radius is involved in calculations.

3. The weights must be gently added and not put carelessly.

Sources of error:—

1. The wire may not be made of homogeneous material.

2. There may be kinks in the wire. These may be removed by the method as explained in the procedure.

Exercises:—1. Find out the weight of a brick with the help of Young's modulus apparatus graphically.

2. Establish graphically the relation between stress and strain.

Oral Questions :—

1. What is the advantage of using two wires and that too very long ?

2. Why do you use kilograms and not grams ?

3. Which is better : to use a thin wire or a thick wire?

4. Define Stress, Strain, Elastic limit and breaking stress.

this is really
a very useful and
good book for each and
every science student
Thinker

CHAPTER X

PARALLELOGRAM AND TRIANGLE OF FORCES, INCLINED PLANE, FRICTION

Every force has a certain magnitude and acts in a certain direction. It is, therefore, possible to represent a force completely by a line, the length of which is proportional to the magnitude of the force and the direction of which represents the direction in which the force is exerted. If the length of an inch be taken to represent a unit force, then a force of 5 units would be represented by a line 5 inches long and two forces of 5 and 3 units acting together in the same direction would be represented by a line 8 inches long. If, however, a body were acted upon by a force of 5 units in one direction and 3 units in the opposite direction, then the effect would be that of a force of 2 units acting in the direction of the force of 5 units, for 3 of the units of this force would be rendered in-operative by the three units acting in the opposite direction.

Parallelogram of Forces. A body can move in one direction at any given instant though it may be acted upon by any number of forces. Each force has a certain magnitude and acts in a certain direction and in consequence of their joint action the body moves with a certain velocity if it be free to do so. A single force which would give the same velocity and produce the samo effect on the body as the separate forces is called the **resultant** of the **forces.** Any system of forces acting upon a particle is equivalent **to** a resultant force. When two forces act upon a body at the same time, their resultant usually can be found by means of the **parallelogram of forces** which may be expressed **thus :—**

If two forces acting at a point be represented in magnitude and direction by the adjacent sides of a parallelogram, the resultant of these two forces will be represented in magnitude and direction by the diagonal of the parallelogram which passes through this point.

The **equilibriant** of two or more forces acting on a body is the single force which acting with them maintains the body at rest. It is evident, therefore, that the equilibriant is equal in magnitude but opposite in direction to the resultant.

Experiment 31 (a). **To verify the law of parallelogram of forces.**

Apparatus.—Gravesand's apparatus, drawing board, clamps, ½ metre rod, wooden or glass block, set-squares, a strip of plane mirror, protractor.

Method.—Take three strings and knot them together at one point. Let one of these strings hang freely and let the

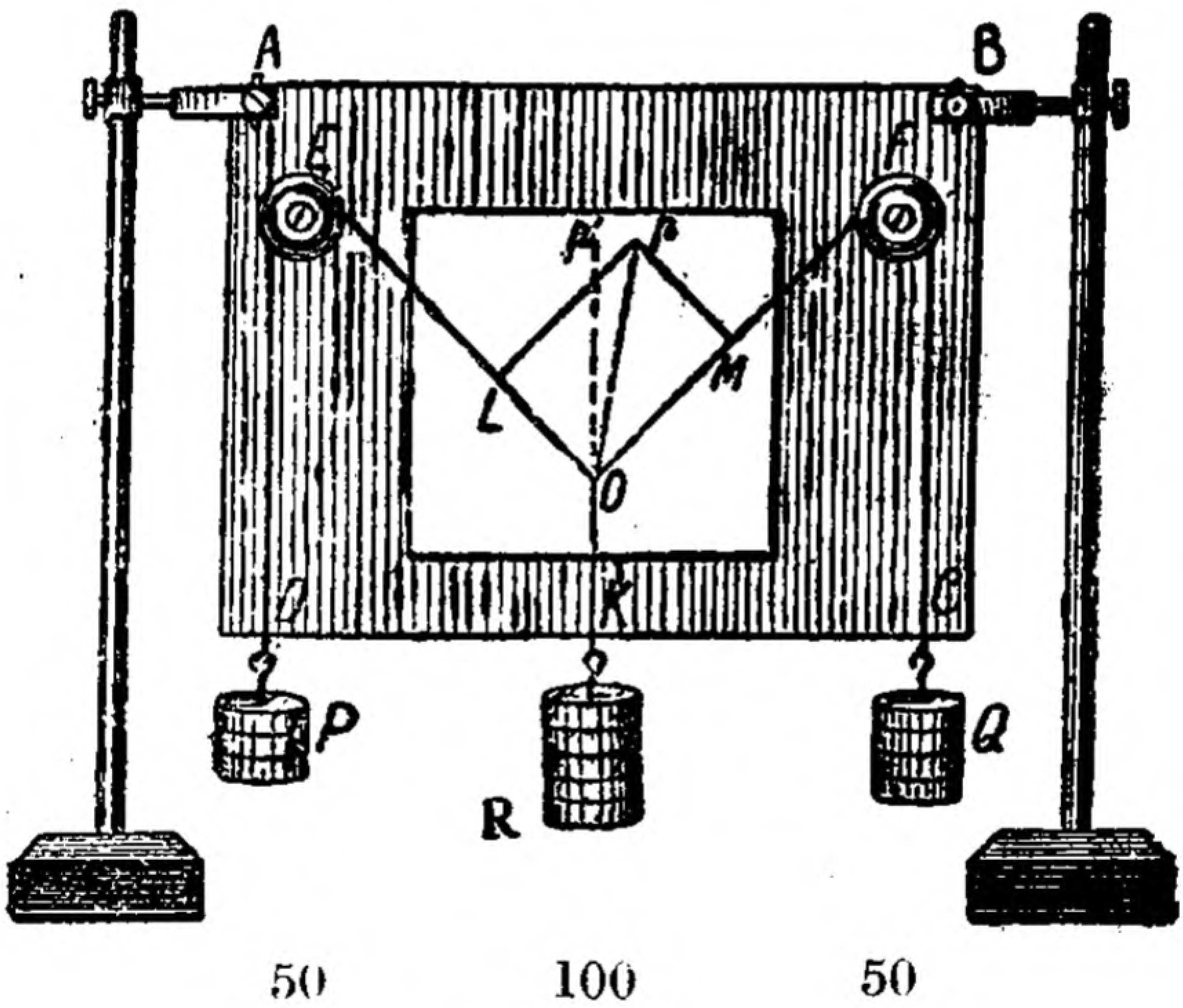


Fig. 45.

two other pass over two pulleys E and F fixed on a drawing board ABCD. Three convenient weights P, Q and R (say 40, 50 and 60 gms.) are attached to three ends of the string and the drawing board is clamped in the vertical position. The weights hung should not touch the board. Fix a paper to the board by means of pins.

To mark the position of the three strings place a strip of plane mirror underneath each of the strings, turn by turn

and mark two points of the string, when your eye, the string and its image in the mirror are in the same plane.

Remove the paper from the board and join the two points marked underneath each string. Produce these lines so that all meet at O. These three lines represent in direction the three forces acting at O and the tension in each string is measured by the corresponding weight attached to it. Select a suitable length to represent a force of 10 gms. (say 2 centimetres). Cut off the lengths OL, OM, OK from O proportional to the three forces, *i.e.*, make OL=8 cms., OM=10 cms. and OK=12 cm. OL, OM and OK represent completely the three forces 40, 50 and 60 gms. weights respectively.Making OL and OM as the adjacent sides complete the parallelogram and draw the diagonal O*p*. This diagonal, therefore, completely represents the **resultant** of the forces P and Q. It should be equal to **OK and in the** same line as OK, the equilibriant **of the two** forces (usually O*p* is not found to be in **the line as** OK, hence draw the line O*p*′ in **continuation with OK**). Measure the length O*p*. The **length O*p* would** be found to be nearly equal to 12 cm. The diagonal **O*p*** thus represents the resultant of the two forces P and Q and if the third force K (60 gms. wt.) which is their equilibriant be removed, the common point would move along *Op*. The diagram should neither be too small nor too long. This can be done by selecting a suitable scale and by adjusting the weights so that the common point of the strings is near the middle of the board.

Take three such observations.

Record thus :—

No. of observation.	Scale chosen for sides of parallelogram	Forces in gms.			Length of sides in cms				Force represented by the diagonal	Angle between OP and OP′
		P	Q	R	OL	OM	OK	Diagonal OP		
1										
2										
3										

Precautions.—1. The board should be fixed vertically.

2. The weights should not touch the board.

3. While marking the direction of the strings do not disturb the position of the strings until you have marked all the points.

4. The zero error of the spring balance should be noted.

5. Weights used should not be small.

Experiment 31 (b). **To verify the law of triangle of forces.**

Apparatus.—The same as in the previous experiment.

Method.—The **law of triangle of forces states**: *"If three forces acting at a point are in equilibrium they can be represented in magnitule and direction by the sides of a triangle taken in order."* On the same sheet of paper used in the previous experiment draw the three lines *ab*, *bc*, *ca*, parallel to the forces P, Q, R respectively. These lines enclose a triangular area. Measure the lengths of the sides of the triangle thus obtained. These three lengths will be found to be proportional to the three forces respectively. Mark by means of arrow-heads the direction of these forces.

Record thus :—

No. of observations.	Forces is gms			Length of sides			Ratios of forces and sides.		
	P	Q	R	*ab*	*bc*	*ca*	$\frac{P}{ab}$	$\frac{Q}{b}$	$\frac{R}{ca}$

Exercise 1. Find the weight of given bag by using the law of parallelogram of forces.

Experiment 31 (*c*)—**Show by an experiment that when three forces acting at a point are in equilibrium each force is proportional to the sine of the angle between the other two forces (Lamis' Theorem).**

Method.—Measure the angles α, β and γ between the pairs of forces and obtain their sines from the tables. Calculate the ratio of each force to the sine of the angle between the other. two. These ratios will be found to be equal. Hence if the three forces on a particle keep it in equilibrium each is proportional to the sine of the angle between the other two.

No. of observation.	Forces in gms.			Angle between the other two forces			Sin α	Sin β	Sin γ	$\frac{P}{\sin\alpha}$	$\frac{Q}{\sin\beta}$	$\frac{R}{\sin\gamma}$
	P	Q	R	α	β	γ						
1												
2												
3												

The inclined plane.—A plane in mechanics is a rigid flat surface and an inclined plane is one that makes an angle with the horizon. Suppose an object O is kept in position upon a smooth plank of wood by a force acting up the plane. The plank may be made smooth by placing a glass plate over its surface. Let the plank be hinged at one end to a horizontal board and placed at an incline. The angle of inclination of the plank can be varied by keeping the movable end of the plank at different heights by supporting the plane on a wooden block which may be placed at different distances from the lower end of the plane. The object is acted upon downwards by a force equal to Mg, P the force exerted along the plane, and R the reaction of the plane acting in an upward direction.

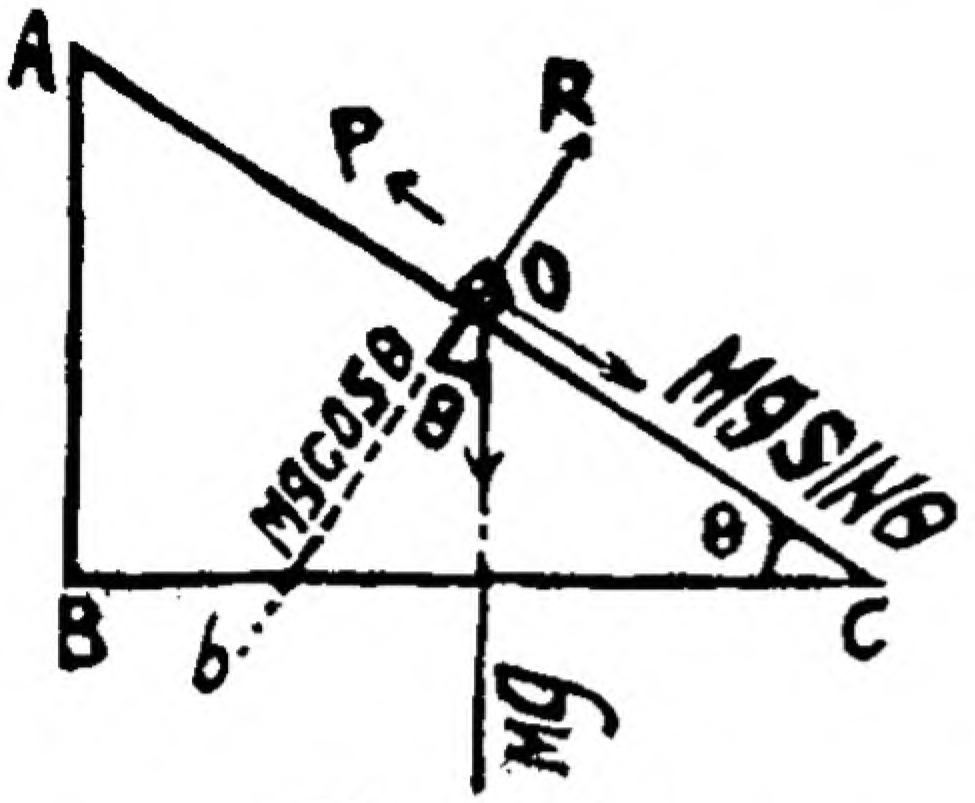


Fig. 46.

Resolving Mg (the weight) perpendicular to the plane and along the plane we get Mg cos θ and Mg sin θ the two components perpendicular to and along the plane. In the position of equilibrium P is evidently being balanced by Mg sin θ and R by Mg cos θ.

$$\therefore \quad P = Mg \sin\theta$$

$$\text{or} \quad \frac{Mg}{P} = \frac{1}{\sin\theta}.$$

Putting W for Mg

$$\frac{W}{P} = \frac{1}{\sin\theta} \qquad \ldots(1)$$

$$\text{But} \quad \sin\theta = \frac{\text{Height of the plane}}{\text{Length of the plane}} = \frac{h}{l}$$

Hence substituting the value of sin θ in (1) above

$$\frac{W}{P} = \frac{l}{h}$$

When the effort or power P acts horizontally, the forces acting on the object O are represented in Fig. 47. The three forces are the weight Mg acting vertically downwards, the reaction perpendicular to the plane and P in a horizontal direction. Since the body can move only along the plane, R has no component along the plane (being at right angles). The weight has a component Mg sin θ acting along the plane in downwards direction and P cos θ, the component of P along the plane in the upward direction. The body would be in equilibrium when these two components are equal.

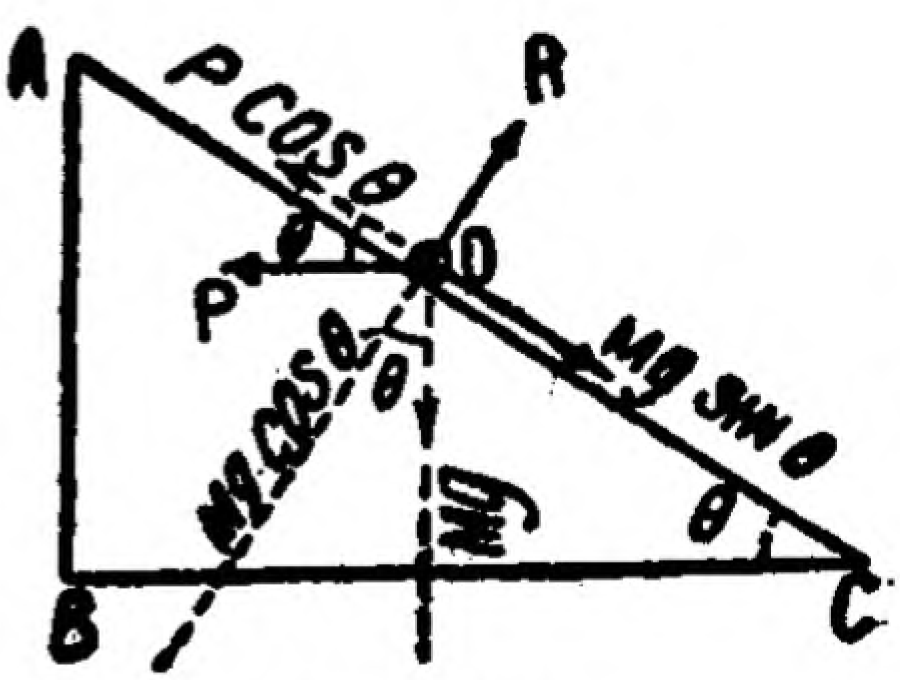


Fig. 47.

$$Mg \sin\theta = P \cos\theta$$

$$P = Mg \tan\theta$$

acc no 788

or P $=W \tan\theta$

$\therefore \frac{W}{P}=\frac{1}{\tan\theta}$

or $\frac{W}{P}=\frac{\text{base}}{\text{perpendicular}}=\frac{b}{p}$.

Experiment 32. **To prove that in the case of the Inclined plane**

$$\frac{W}{P}=\frac{l}{h}$$

i.e., mechanical advantage $\left(\frac{W}{P}\right)$=velocity ratio $\left(\frac{l}{h}\right)$.

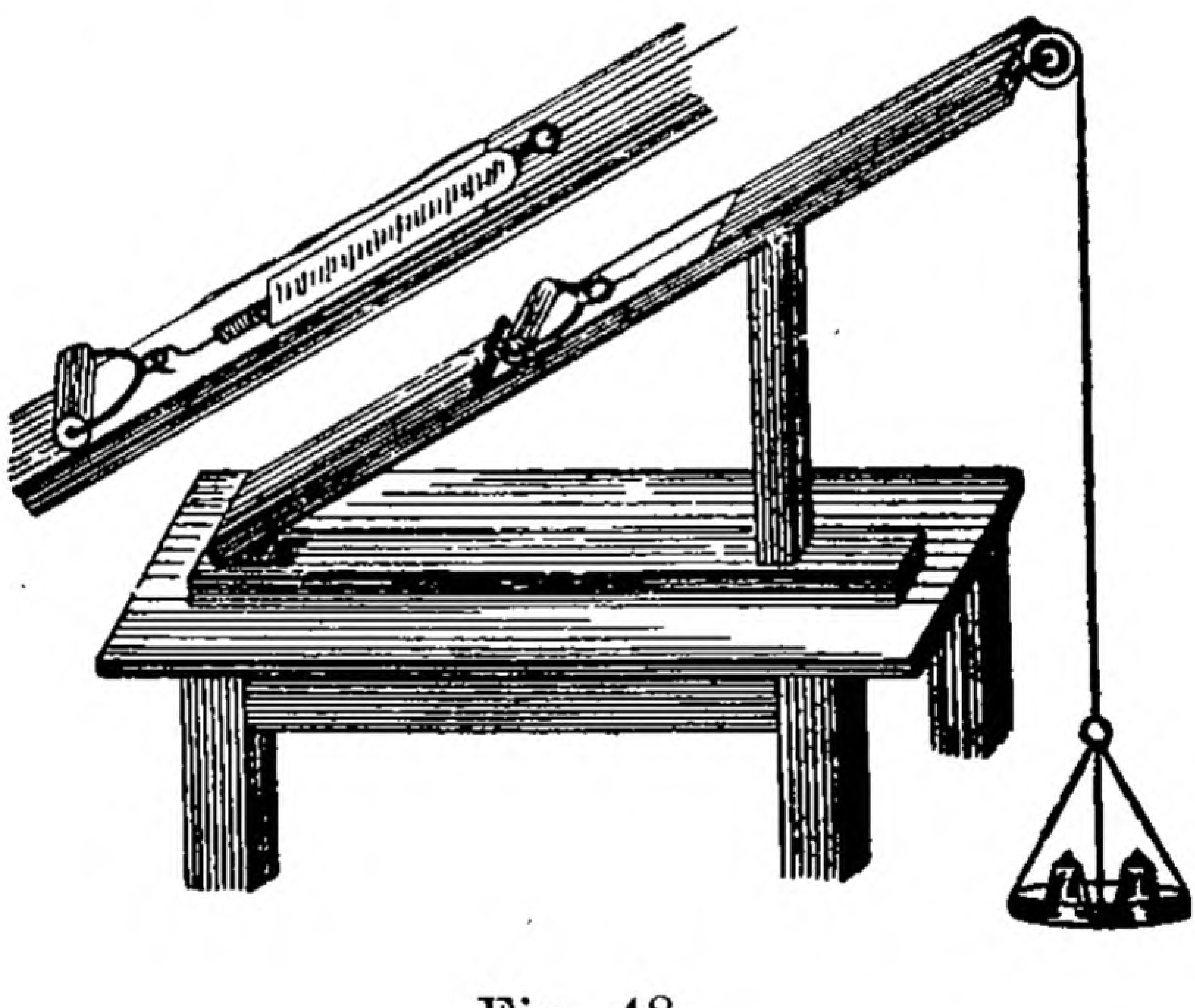


Fig. 48.

Apparatus.—Inclined plane, weight box, pan and roller connected by a string, spring balance, a metre rod, a plumb line, pulley system.

Method.—Take a heavy metallic cylinder which can roll up or down the plane. Let it be connected with a string which after passing over a pulley is connected to a pan in which weights are put. Power in this case acts along the plane. The pulley is fixed at the movable end of the plane. The weight of the empty pan and the weights in it give P. But when a spring balance is used instead of a pan

and weights, the readings of the spring balance which is attached to the cylinder give us P.

Support the plane on a wooden block so that it is inclined at angles of 30° to 45° approximately and hold the cylinder on the plane and pass the string over the pulley at the end. Add weights to the pan and tap the plane a little till the cylinder just moves up the plane. Record these weights. Now take away weights from the pan tapping it as before till the cylinder just begins to move down. Take the mean of these weights and add to them the weight of the scale pan. This gives us P, the power. Make by means of a plumb line two points one on the inclined plane (lower surface) and the other on the base (upper surface). Measure the height between these two points by means of a metre stick. The length of the plane will be from this point to the hinged point.

Or, measure the vertical height from the wooden plane at the point where the wooden block cuts the lower surface of the plane. After recording this height measure the distance from the hinged end. These measurements, therefore, give us the height and the length of the plane.

Record thus :—

Weight of the empty pan =

No. of observation	Effort P			Power P= mean wts. + wt. of scale pan	Weight (W) of the cylinder	Height (h)	Length (l)	$\frac{W}{P}$	$\frac{l}{h}$	% difference
	When moves up	When moves down	Mean							
1										
2										
3										

Precautions :—1. Tap the upper glass plate over which the cylinder moves a little so that the cylinder may not stick on account of friction.

2. Mark by means of a plumb line two points, one on the inclined plane and the other on the base. Measure the height between these points, and the length of the inclined plane from this point to the hinged point.

3. To eliminate errors due to friction readings of P are taken when the roller is about to move up and down, two such readings being taken for each inclination.

4. See that the string is parallel to the edge of the plane.

5. The roller should always begin to move up or down from the same point. This point should be marked along the edge of the plane.

6. In order to get good results the difference between the weights when the roller moves up or down should not be very great.

Exercises. (1) Plot a curve to show the relation between P and Sin θ for a smooth inclined plane when the power acts along the plane.

(2) Determine the weight of the roller by using a smooth inclined plane.

(3) Determine the mechanical advantage of (1) a lever, (2) the pulley system.

(4) With the help of inclined plane, verify Newton's second law of motion.

[*Hint.* If F=Ma, the weight of a body of mass M is equal to Mg and the component of the force acting in the downward direction is Mg sin θ and its acceleration is equal to g Sin θ. Suppose the body covers a length l in t seconds.

Now $l=\frac{1}{2}\, g \sin\theta\, t^2=\frac{1}{2}\, g\, \frac{h}{l}\, t^2.$

$\therefore\ ht^2=\frac{2l^2}{g}=$constant. If we prove that for different heights ht^2 is constant, then F=Ma.]

Friction

When a rectangular wooden block is resting on a horizontal table a small force may be applied horizontally to the block without causing it to move. The reason for the block remaining at rest is that the force applied to it is neutralised by an equal and opposite force which tends to keep the block at rest and is located between the two surfaces in contact. This latter force may be expressed more accurately as a stress and it is called into play by friction between the two surfaces. If the applied force be now gradually increased till the block is just on the point of sliding, then the force of friction at this point is called the **limiting friction**. If a spring balance be attached to the wooden block and the balance be pulled slowly in the horizontal direction, the value of the applied force when the block is on the point of moving gives the limiting friction.

(1) The magnitude of the limiting friction is directly proportional to the normal reaction between the two surfaces.

(2) The magnitude of the limiting friction between two bodies is independent of the area and the shape of the surfaces in contact so long as the normal reaction remains the same.

Co-efficient of friction is the ratio of the limiting friction to the normal reaction between two surfaces. It is a constant quantity for any given pair of surfaces.

Experiment 33.—**To determine the co-efficient of friction between glass and wood.**

Apparatus.—An inclined plane having a glass top, a wooden tray, weight box, spring balance, string, scale-pan, metre rod.

Method I. Set the wooden plank having a glass plate on it horizontal and place on it the wooden tray. Attach one end of the string to the wooden tray and the other (after allowing it to pass over a horizontal pulley) to a scale pan. Adjust the pulley in such a manner that the string from the hook of the tray which passes over the pulley is quite horizontal. Put weights in the scale pan

till the tray just begins to slide. Next, place a known weight in the tray and add weights in the pan till the tray again begins to move. Go on adding weights in the tray as well as in the pan and repeat the operations. The weight of the tray plus the weight placed in it is equal to the normal reaction. The limiting friction is equal to the weight of the scale pan and the weights added to it to

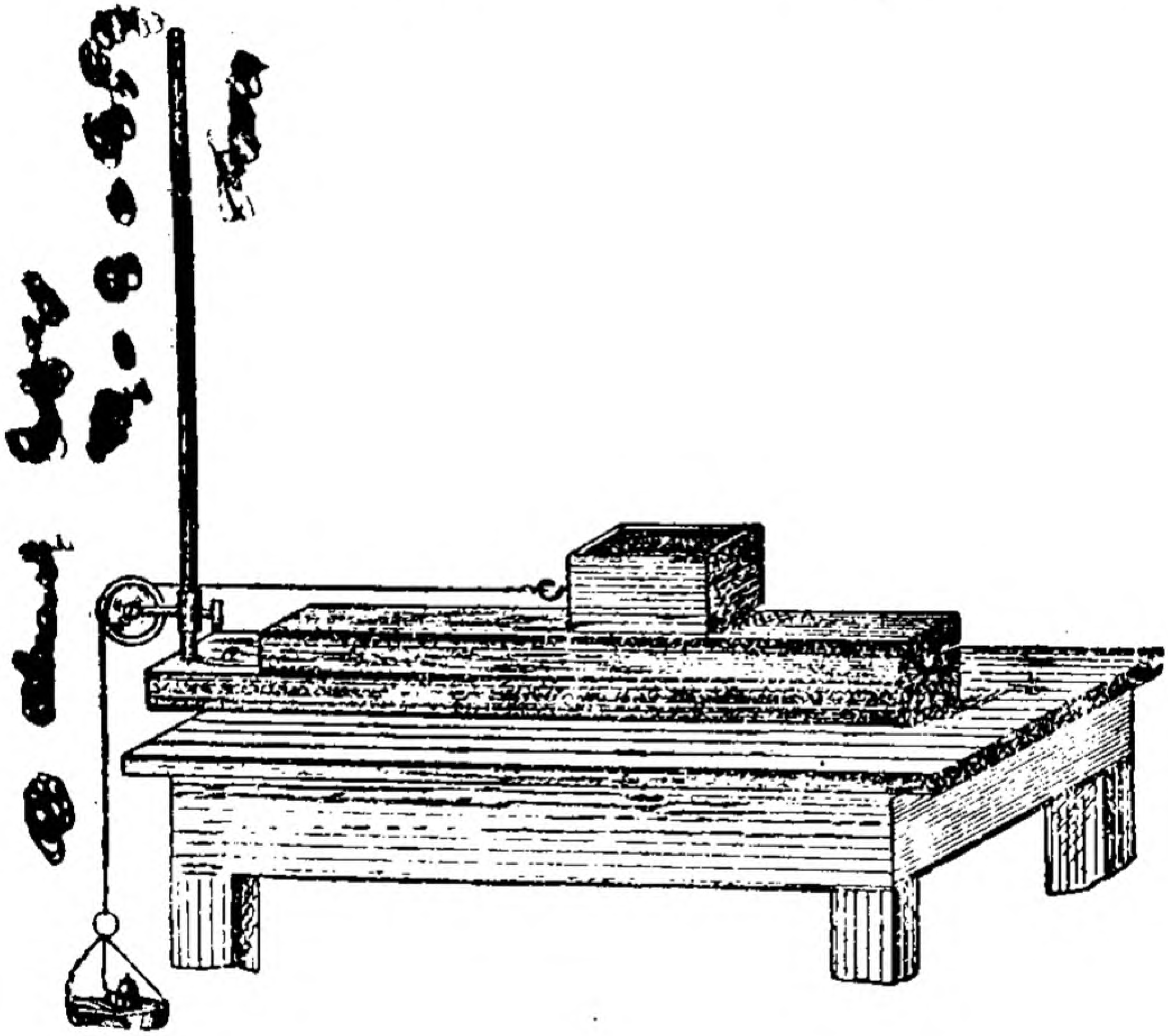


Fig. 49.

produce sliding. It will be seen from the results of the experiment that the ratio of the limiting friction to the normal reaction is always constant.

Record thus :—

The weight of the empty tray=

" " scale pan=

Additional weights in the tray	Weights added to the pan just to produce sliding	Normal reaction R	Limiting friction F	$\mu = \frac{F}{R}$

Precautions.—1. Get the wooden plank having a glass plate on it horizontal and then place the wooden tray over it.

2. Tap the glass plate a little to start the tray moving; this is done to avoid the sticking of the tray to the sides of the glass plate.

3. Adjust the pulley in such a manner that the string from the hook of the tray which passes over the pulley is quite horizonal.

Method II.—(Inclined plane method.) Place the tray on the plane glass surface and gradually increase the inclination of the plane till the tray just begins to slide down. (Fig. 50) The angle of inclination can be changed to different values by changing the position of the wooden block supporting the inclined plane.

It will be seen that there are three forces in equilibrium; the limiting friction (F), the reaction R, and the weight of

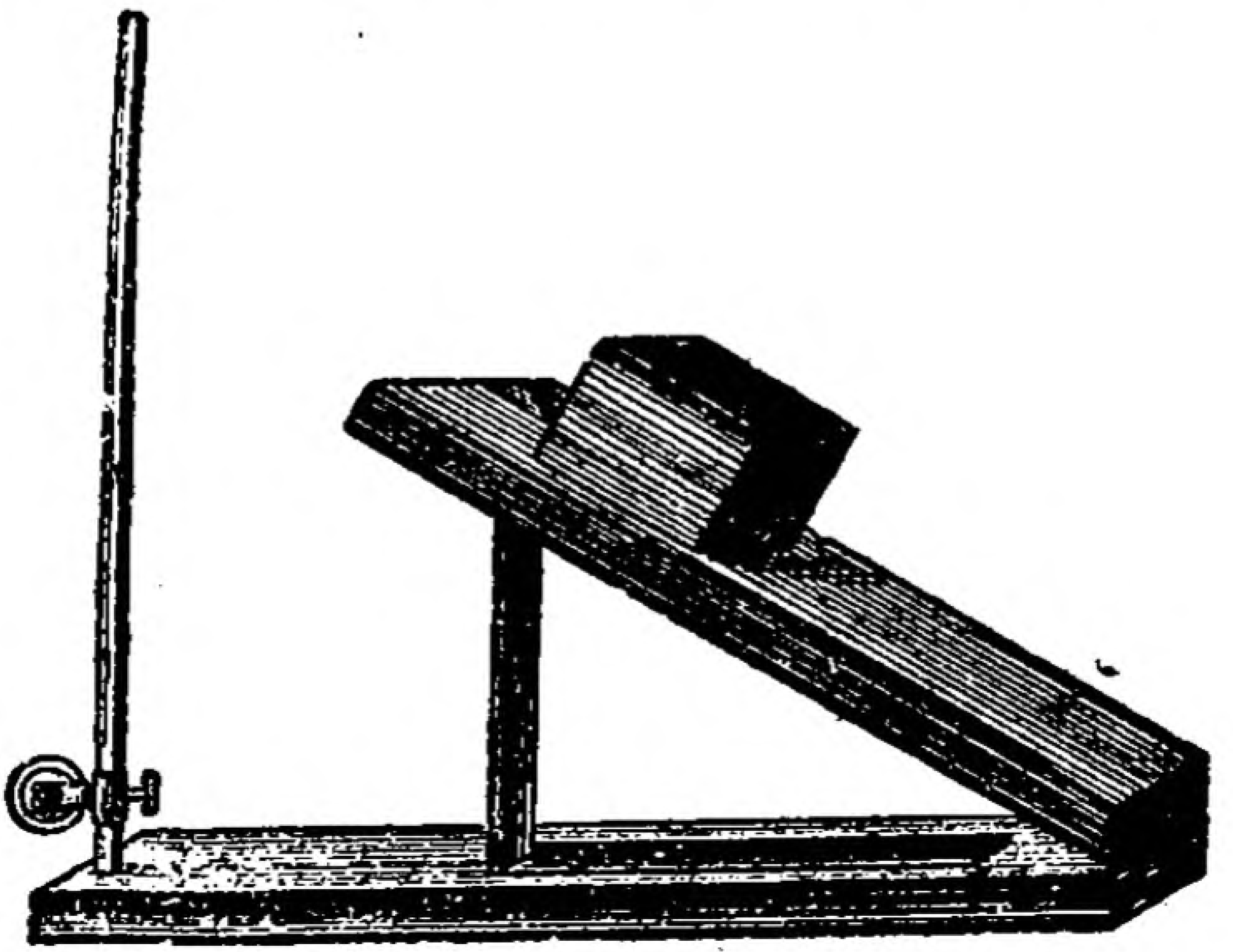


Fig. 50.

the block mg. (Fig. 51). Resolve mg along and perpendicular to the plane ; then

$F = mg \sin \alpha$......(*i*)
$R = mg \cos \alpha$......(*ii*)

Dividing (*i*) by (*ii*)

$$\frac{F}{R} = \tan \alpha$$

$$\frac{F}{R} = \mu \text{ (already proved.)}$$

$= \tan \alpha$ (α being the inclination.)

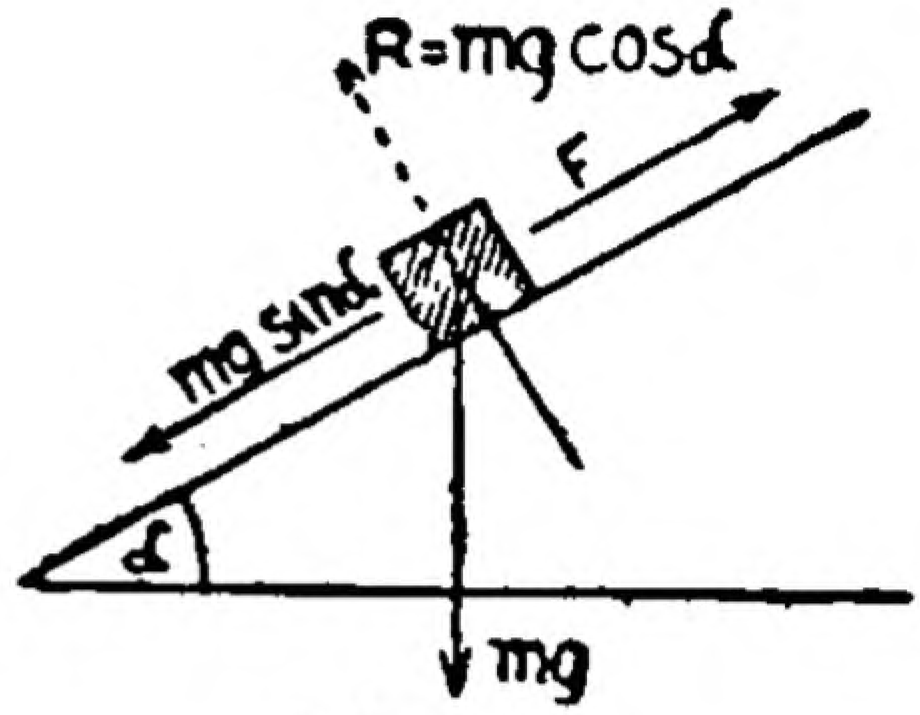


Fig. 51.

But $\tan \alpha = \dfrac{\text{height of the plane}}{\text{base of plane}}$.

Measure the height and the base of the plane by a plumb line (as already mentioned). The ratio is the co-efficient of friction between glass and wood.

Now add weights in the tray and gradually vary the angle of the plane till the tray just begins to slide down. It will be seen that the inclination is the same.

Record thus :—

Weight of the tray=

No. of observations	Weights added in the tray	Total mass	Height h	Base b	$\mu = \frac{h}{b}$	Mean

Precautions :—1. Measure the height of the plane by **plumb line.**

2. The plane may be tapped a little if necessary.

CHAPTER XI

CENTRE OF GRAVITY

THE LEVER—PARALLEL FORCES

Centre of Gravity. The centre of gravity or C. G. of a body is the point where the whole weight of the body is supposed to act. A body balances if it is itself supported at its C. G. (hence also called the balancing point). If a body is freely suspended from a support it will come to rest with its centre of gravity vertically below the point of support. Similarly, if the body be suspended from another point, the vertical line through this point will also pass through the C. G. Hence the point where this line crosses the first is the C. G.

Experiment 34. **To find C. G. of a flat plate or a piece of card-board.**

Apparatus. Plumb line, set squares, pins, metre rod, flat plate or card-board.

Method. Suspend the flat plate by making a hole near its edge so as to allow a pin to pass through it horizontally. See that the plate can swing freely on the pin. Hang a plumb line on the pin and quite close to the plate without actually touching it. Make two marks on the plate immediately behind the plumb line taking care not to displace either the plate or plumb line.

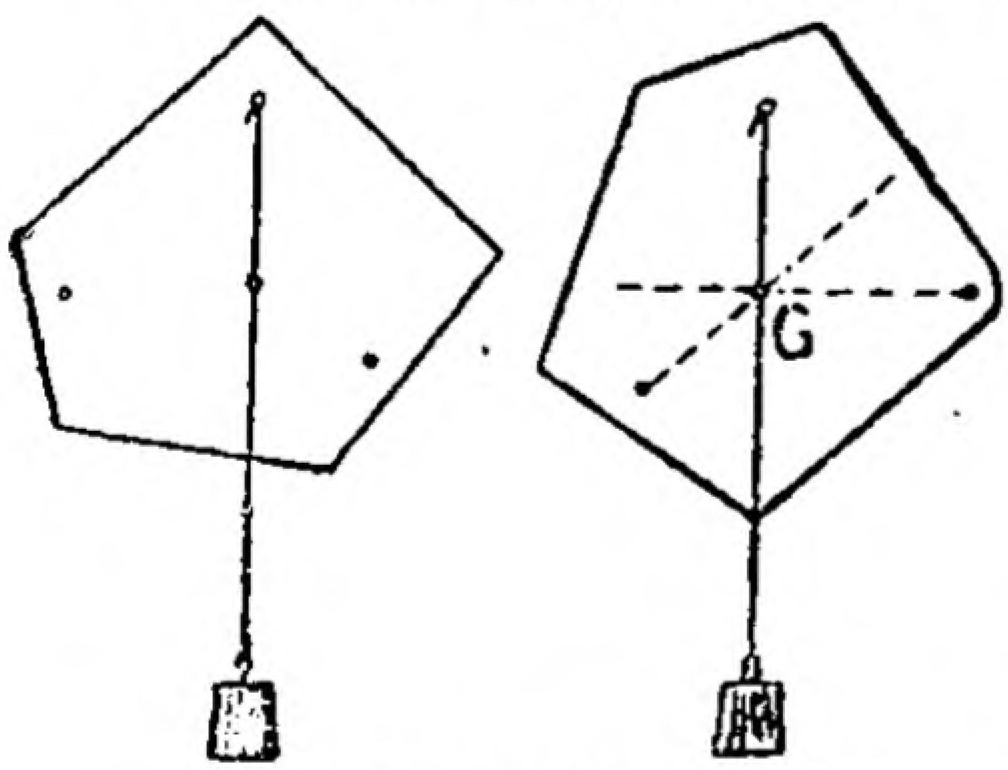


Fig. 52.

Remove the plate and draw a fine line joining the marks. Hang the plate from another point and repeat the previous process. We thus obtain another line which crosses the first. The point of intersection of the two lines is the C. G. Suspend the plate at a third point and again draw a third line as before. The third line will also intersect the other two at the same point. It will be found that the plate can be balanced at this point.

Precautions.—1. The plate should swing freely on the pin fixed horizontally.

2. The plumb line should be quite close to the plate and should not touch it.

The Lever. A lever is a rigid bar which can be turned freely about a fixed point. The fulcrum of the lever is the fixed point about which the lever can be turned. The force exerted when using a lever is often described as the power, and the body lifted or the resistance overcome as the weight. The perpendicular distances from the fulcrum to the lines of action of the forces acting upon a lever are known as the arms of the lever. It will be seen that

wt. on one side of the fulcrum × Perpendicular distance from the fulcrum = wt. on the other side × Perpendicular disance from the fulcrum.

Each of these products is termed the **moment** of the force about the fulcrum. Hence the tendency of a force to turn a body round a fixed axis, is called the moment of that force round the fixed axis, and is measured by the product of the force and the perpendicular distance between the axis of rotation and the line of action of the force.

When two or more forces act on a body, their turning effect is measured by the sum of their separate moments. If the moments tend to turn a body anti-clockwise, they are called positive; and those which tend to turn the body clockwise are called negative.

Experiment 35. **To prove that when a lever is in equilibrium under the action of two or more forces the sum of the moments tending to turn it clockwise round the fulcrum is equal to the sum of the moments of forces tending to turn it anti-clockwise.**

Apparatus. Metre rod, weight box, wedge, thread.

Method. Balance the metre rod on the wedge placed on a wooden block and take the readings of the balancing point so that it can be replaced if accidentally moved. This point is the C. G. of the rod. Hang a weight of 50 grams at a certain distance from the fulcrum on the left-hand side.

Suspend another weight, say 20 grams at some convenient distance on the right hand side so that the rod is balanced, *i.e.*, becomes horizontal. The weights should be suspended by making a loop of the thread as it is easy to balance the rod and to read the position of weight on it.

Next keeping the 50 grams weight on some other point on the left-hand side suspend two weights on the right-hand side, *i.e.*, 20 grams and 10 grams, at different distances so that the rod is horizontal. Repeat the experiment using two different weights on the right-hand side and one on the left.

Record thus :

Balancing point of the metre rod=

No. of observations	Right-hand side			Left-hand side		
	Forces	Position of forces	Sum of Moments	Forces	Position of forces	Sum of Moments
1						
2						
3						
4						
5						

Precautions :—1. The C. G. of the metre rod should be determined accurately by placing it over a wedge.

2. The weight should be suspended by making loops of thread as it is easy to balance the rod and to read the position of the weight on it.

3. The metre rod should be made horizontal in the equilibrium position.

4. Weights used should not be so large as to bend the lever.

5. The top part of the loop should be perpendicular to the rod.

Exercise. Find out the weight of a piece of brick by the principle of moments.

Experiment 36. **To determine the weight of a metre rod.**

Apparatus. The same as in the previous experiment and a spring balance.

Method. Find out the C. G. of the rod by balancing it on a wedge. Place the metre rod on wedge making some other point but the C. G. as the fulcrum.

Suspend a weight by a loop of thread on the shorter arm at such a distance that the rod may be balanced. Note down the position of the weight and that of the fulcrum. Now take moments round the fulcrum. Read the distance between C. G and the fulcrum very accurately, as the weight of the rod is obtained by dividing the moment on the other side by this distance. Repeat the experiment by making different points as the fulcrum and suspending different weights at different points from the fulcrum. Now placing the rod at some other point (fulcrum) but not at its C. G. we have

Weight of the metre rod acting at its C. G. × distance of C. G. from the fulcrum = the weight suspended × distance of that weight from the fulcrum.

∴ Weight of the metre rod

$$= \frac{\text{Weight suspended} \times \text{its distance from the fulcrum}}{\text{Distance of C. G. from the fulcrum}}$$

Record the result in a tabular form.

Record thus :

Position of C. G. of the rod = (1) (2)

Mean

No. of observations	Weight suspended	Position of fulcrum	Distance of the weight from the fulcrum	Distance of C. G. from the fulcrum	Weight of the metre rod

∴ Mean weight =gms. (calculated.)
Wt. with spring balance=gms. (observed.)
Error =

Precautions :—Observe the same precautions as given in the last experiment.

Exercise 1. Verify the principle of moments by a metre rod taking the fulcrum at 30 cms. mark.

Exercise 2. Suspend a heavier weight from the shorter arm and lighter weight from the longer arm and adjust the position of the weights till the scale balances. Plot a graph between the moments of the two weights about the point of suspension and deduce from the graph the weight of the metre rod assuming that its C. G. is at its centre.

Exercise 3. By using a lever determine the relation between a gram and a ounce.

Experiment 37.—**To determine the density of a solid piece and a liquid using a counterpoise by the application of the principle of lever.**

Apparatus. A uniform wooden rod with hole bored at C. G., a knitting needle, a glass stopper, thread, kerosene oil in a beaker.

Method. Suspend the uniform wooden rod by passing the knitting needle through a hole bored at its C. G. so that the rod turns freely in a vertical plane. Suspend the glass stopper by means of a thread at a distance from the fulcrum; suspend a weight on the other side by means of a loop of thread and move this weight till the rod is horizontal. Determine from these readings the weight of the glass stopper. Next suspend the glass stopper in a beaker of oil. Determine the weight of stopper in oil. After cleaning the stopper, suspend it in a beaker of water and determine the weight of stopper in water. *See that the rod remains horizontal during these weighings.* Calculate the loss in weight undergone by the stopper in the two liquids.

Record thus :—
Position of fulcrum=
Temp. of oil =
Temp. of water =

No. of observations	Wt. suspended	Dist. of wt. from the fulcrum	Moment	Dist. of stopper from fulcrum	Wt. of stopper in air.	Wt. of stopper in oil	Wt. of stopper in water	Loss of wt. in oil	Loss of wt. in water
1									
2									
3					Mean	Mean	Mean		

$\therefore$ Density of stopper $= \dfrac{\text{Wt. in air}}{\text{Loss of wt. in water}} \times$ density of water at room temperature.

Density of oil $= \dfrac{\text{Loss of wt. in oil}}{\text{Loss of wt. in water}} \times$ density of water at room temperature.

Precautions. Observe the same precautions as in density experiments and in lever experiments.

Parallel Forces

We have already learnt that if the forces are in the same plane, we can use the law of parallelogram, or triangle or polygon of forces to find out the resultant. But let us see what will be the case when the two forces do not meet, in other words when they are parallel to each other. The above— mentioned constructions will fail. When all the parallel forces are in the same direction they are said to be *like parallel* forces, but on the other hand when some of the forces are in one direction while the others are in the opposite direction, they are said to be *unlike parallel* forces.

Experiment 38. (*a*) **To find the magnitude and the point of application of the resultant of two like parallel forces.**

(*b*) **To verify the condition of equilibrium of three parallel forces.**

Apparatus.—Two spring balances, stands, thread, weight box, a metre rod, a $\frac{1}{2}$ metre rod, a wedge.

Method.—Balance the metre rod at the wedge and find out its C. G. Next weigh it by a spring balance and get the mean of *at least* two readings. If there be any zero error present, apply the necessary correction.

Suspend the metre rod edgewise in two loops of thread fixed to two spring balances. Arrange the two balances vertically at different distances from the C.G. See that the metre rod is horizontal and the balances are in the same vertical line with their loops. This can be tested by taking the height of each end of the metre rod by the help of another metre rod.

Suspend by means of another loop a weight of 100 gms. from the C. G. Read the two balances and the position of the loops of their respective hooks on the metre rod. Change the middle weight at the C. G. and also the position of the spring balances from the C. G. of the metre rod. After seeing the rod to be horizontal, read again the position of the balances. Repeat the experiment four or five times.

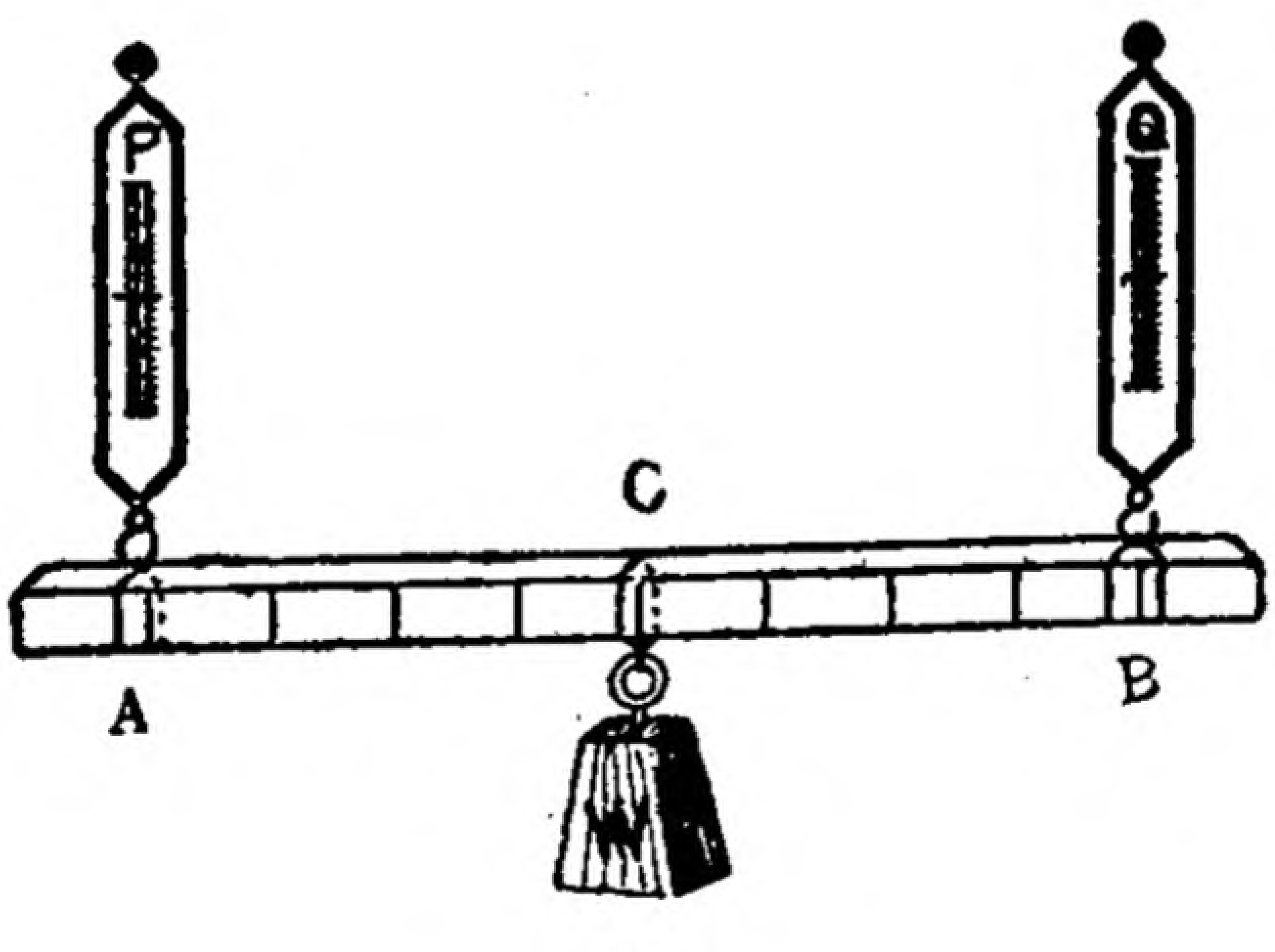


Fig. 53.

Record thus :—

Reading of the C. G. of the metre rod=

Weight of the metre rod applying zero correction=

(1) (2) Mean=

No. of observation	Wt. suspended at C	Spring balance P			Spring balance Q			Suspended weight + weight of metre rod, i. e., P + Q = Resultant
		Reading of P	Distance of P from C.G., i.e., AC	P × AC	Reading of Q	Distance of Q from C.G., i. e., BC	Q × BC	

It will be seen that the total downward force is equal to the sum of the two upward forces. The downward force is the equilibriant force and the resultant is equal and opposite to this. The resultant acts at C, which divides the distance between the two forces P and Q internally in the inverse ratio of the forces,

$$i.\ e.,\ P \times AC = Q \times BC.$$

(*b*) **For verifying the condition of equilibrium of three parallel forces show that $\frac{P}{BC} = \frac{Q}{AC} = \frac{R}{AB}$ and that $P+Q$ is equal to R where R is equal to the weight of the rod and the weight suspended from it at the C. G.**

Enter your observations as follows :—

No. of Observation	Forces			AC	BC	AB	$\frac{P}{BC}$	$\frac{Q}{AC}$	$\frac{R}{AB}$	P+Q	R
	P	Q	R								
1											
2											
3											
4											

Precautions.—1. The metre rod should be suspended edgewise in loops of thread.

2. The metre rod should be horizontal and spring balances with their loops vertical.

3. The zero error of the spring balance must be taken into account.

4. Readings of the spring balance should be taken only when they are well adjusted.

Resultant of unlike parallel forces.—Since the three forces P, Q and R are in equilibrium, any one of them can be considered as equal and opposite to the resultant of the other two, *i. e.*, in the last experiment we can consider P and R as the two unlike forces, the force equal and opposite to Q becomes the resultant. It is nearer to the greater force. Q the equilibriant acts in the upward direction.

Experiment 39. **To find out the magnitude and position of the resultant of two unlike parallel forces.**

Apparatus.—The same as in the previous experiment.

Method.—Arrange the experiment in a similar manner using different weights at the C. G. and keeping the spring balances at different position from the C. G. *Keep the metre rod always horizontal.*

Record thus :—

Position of C. G. of the rod=

Weight of the rod=(1) (2)

Mean=

No. of observations	Weight suspended Reading of P	AB	P×AB	Total downward force R	BC	R×BC	Resultant = R − P	Reading of Equilibriant. Q

The resultant is parallel to each of the forces and is in the direction of the greater force and is equal to the difference of the two forces.

Exercise.—Verify the principle of moments for parallel **forces.**

Experiment 40.—**When a number of parallel forces are in equilibrium to compare** (*a*) **the total force in one direction with the total force in the opposite direction.** (*b*) **the clockwise moments with the counter-clockwise moments.**

Apparatus —Metre rod, three spring balances, stands, thread, weight-box, etc.

Method.—For finding out the weight and C. G. of the metre rod proceed as in the previous experiment.

Suspend the metre rod edge—wise in three loops of thread fixed to the three spring balances, vertically at three different positions from the Centre of Gravity (G) two near the ends and one in the middle near G.

See that the metre rod is horizontal and the balances are in the same vertical line with their loops. This can be tested by taking the height of each end of the metre rod by means of another metre rod.

Suspend by means of two other loops two convenient weights (say W_1 gms. and W_2 gms.) from different points.

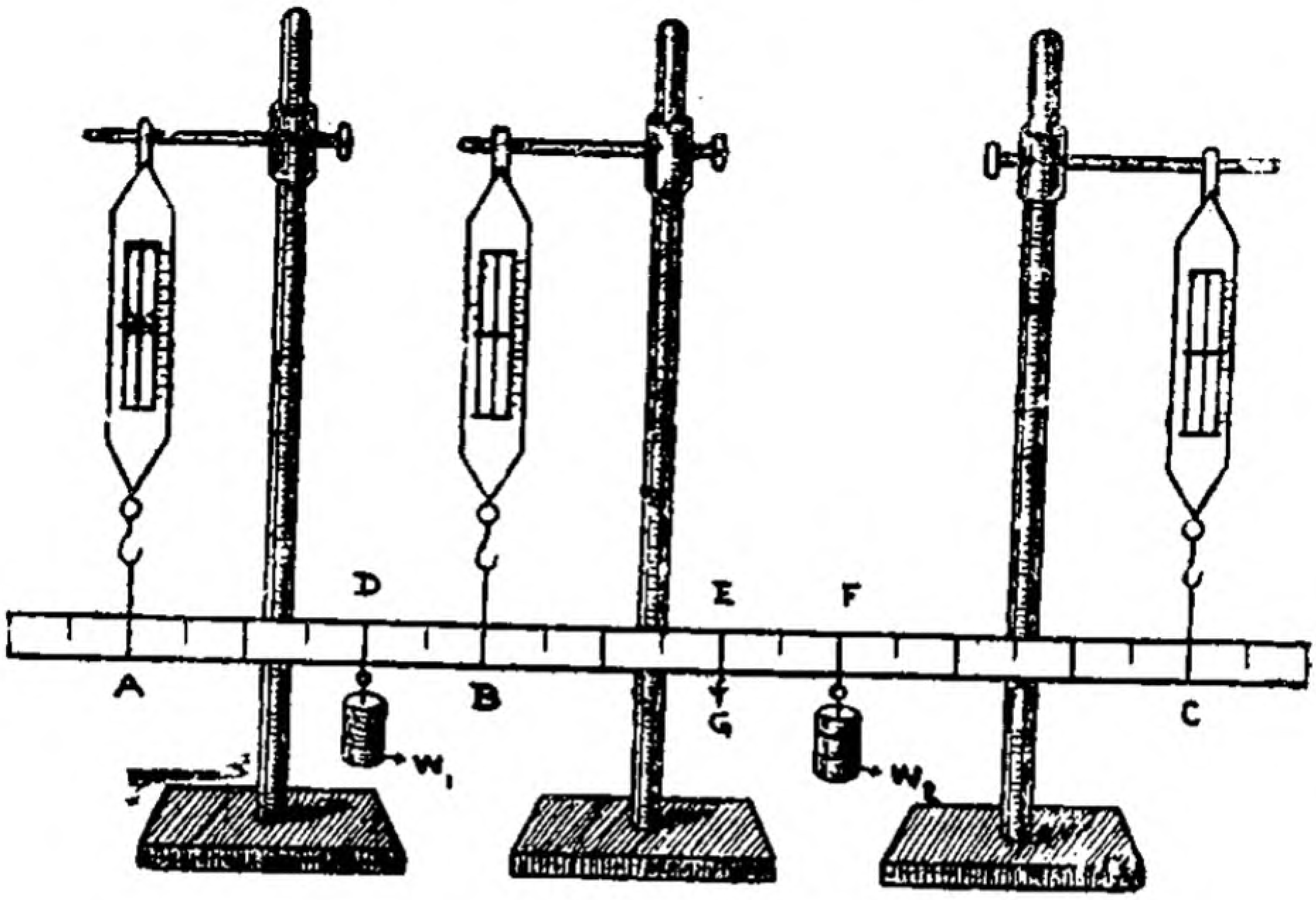


Fig. 54.

Read the three spring balances and the position of their respective loops on the metre rod. Read also the position of the loops by which the weights are suspended.

Change the position of the weights and of the spring balances. After making the rod horizontal read again the position of the balances and weights suspended.

Record thus :—

Reading of C. G. of the metre rod =

Weight of the metre rod applying zero correction =
(1) (2) mean =

(*a*)

Weights suspended			Spring balances		
Magnitude of weights	Distance of weight from C. G.	Total downward force	Reading of spring balances	Distance of spring balance from C. G.	Total upward force
W_1 W_2 Wt. of rod			A B C		

(*b*)

Taking moments about C. G., *i.e.*, the point E.

Clockwise moments	Counter-clockwise moments
Moment of A=	Moment of C =
Moment of B=	Moment of D =
Moment of F=	Total counter-clockwise moments=
Total clockwise moments=	

Repeat the observations twice as above.

CHAPTER XII

ACCELERATION DUE TO GRAVITY

Simple Pendulum.—A simple pendulum consists of a heavy metal bob usually a metal ball 2 to 3 cms. in diameter attached to a piece of inextensible string of negligible weight. The free end of the thread is held between the halves of a split cork which can be supported in a retort stand and clamped on the table so as to be at a height of 4 or 5 feet from the floor. If such a pendulum be displaced to one side and then let go it oscillates backwards and forwards about its vertical position under the action of gravity. This to and fro motion of the pendulum from one extreme end to the other and back again to the first is called a **vibration**. The maximum distance travelled by the pendulum from its mean to the extreme position is called the **amplitude** of vibration. Each vibration takes exactly the same time if the amplitude is not large. The length of the pendulum is the distance from the point of support (lower edge of the two halves of the cork placed evenly) to the centre of the bob. The time taken by the pendulum to complete one vibration is called the **time period** or simply the period of vibration. As the time passes the amplitude of the pendulum goes on decreasing but the period remains the same. This fact is expressed by saying that the movements are **isochronous**.

The period of a pendulum vibrating with a small amplitude depends on its length and the value of acceleration due to gravity g at the place. The mass of the bob does not affect the period.

The amplitude so long as it is small does not affect the time period.

The relation between the time period t, length l and acceleration g is $t=2\pi\sqrt{\frac{l}{g}}$. If, however, the amplitude is larger the time period is more than this.

Experiment 41. (1) **To find out the value of g. (2) to plot a curve between l and t^2 and to find the length of a second's pendulum.**

Apparatus.—Simple pendulum, two halves of a cork, stop watch or clock, metre rod, gum paper, a piece of chalk, calipers, etc.

Method.—Find the diameter of bob with vernier calipers. Tie a thread about 120 cms. to the bob and place the free end of the thread between two halves of a cork which can be held together between the clamp of a retort stand. With a piece of chalk draw two lines on the floor, one parallel and the other at right angles to the edges of the table and adjust the position of the stand so that the bob is just over the point of intersection of these two lines. Hold the bob of the pendulum between your thumb and the forefinger, and pull the bob about 6 cm. to (making an angle of about 3° with the vertical) one side and let it go without a push. If the bob moves along the line drawn parallel to the table it is properly swinging and if not moving like this stop it and try again. Take a position in front of the pendulum thread and place your finger on the lever of the stop clock or watch. The position of the second's hand in the case of a clock should be noted or better fix the position of the index hand parallel to it to mark the starting point. Watch the movements of the bob for some time to see that you can follow the movements well. When it just crosses the point of intersection of the two lines (say from left to right) say **nought** or **zero** and press the lever of the watch or clock with the finger. When the bob crosses a second

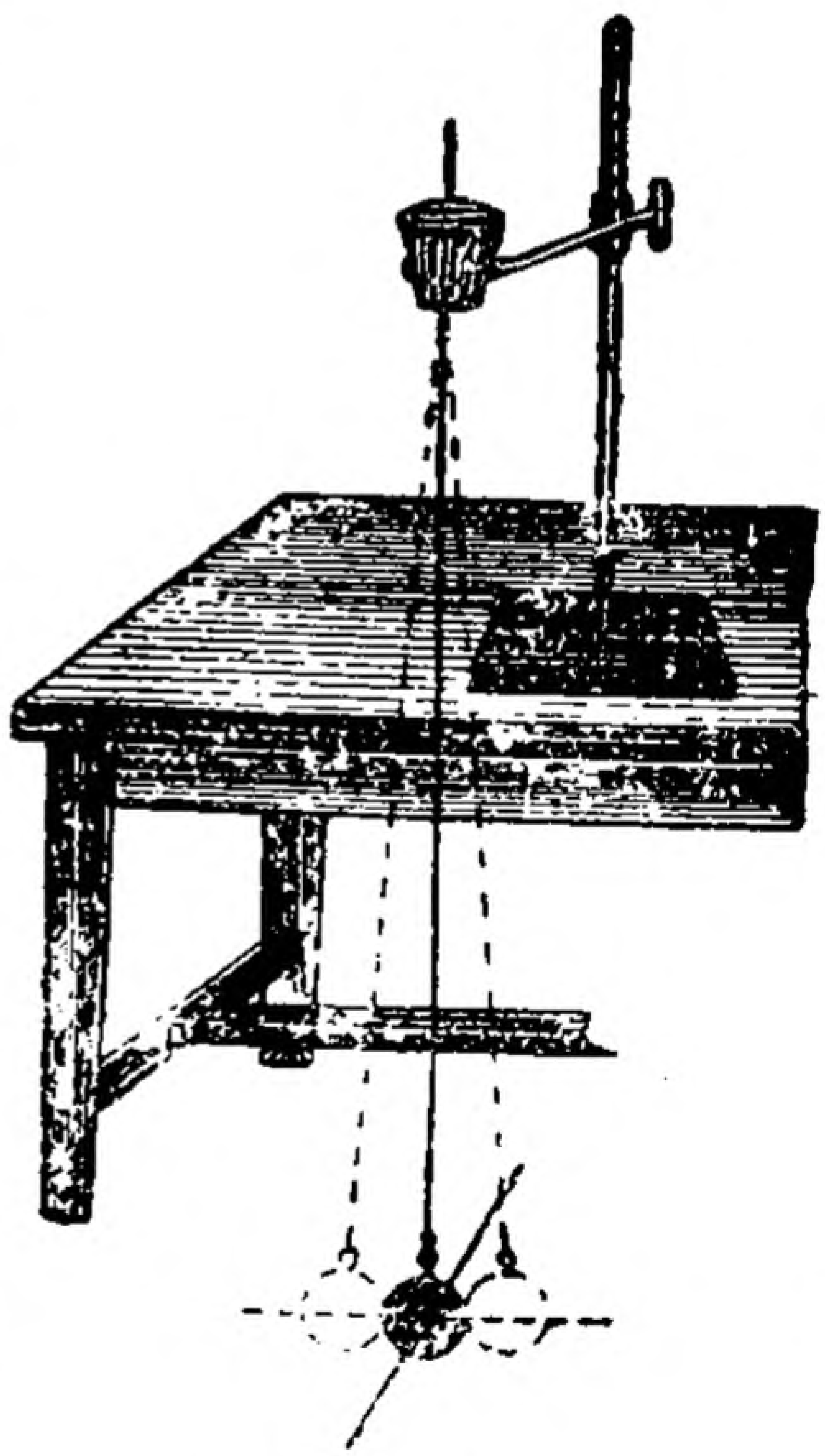


Fig. 55.

Find the length of second's pendulum from the graph. A second's pendulum is that whose time period is equal to two seconds.

Precautions.—1. A very common error made by the students is to count one at the start instead of zero, *i.e.*, when the bob passes through the mean position to the right or left *begin counting always with zero and not one.*

2. The amplitude must always be small (not exceeding four degrees in any case).

3. Cork pieces should always be in level at the bottom.

4. The bob should move in a plane.

5. Use vernier calipers to measure the radius of the bob.

6. For calculating the value of g, take observations with greater lengths as the time can be measured more accurately when they are large.

7. The number of vibrations should be 20 if length exceeds a metre and increased to 50 so as the length diminishes.

8. Time should be noted at least twice with one length.

9. The length should be changed by more than 10 cms.

Experiment 42.—**Find the length of an inaccessible pendulum.**

Apparatus.—A stop watch or clock, gum paper, drawing board, chalk, calipers, etc.

Method. Take the time for 20 vibrations with the unknown length (l) and find the time period (t). Decrease the length by some definite amount (call it x). If the pendulum has been raised from the floor, fix a board underneath the bob at a distance of 1 cm. from the bob and draw the cross over it. Take again the time period for 20 vibrations and get the time period t_1 as before. For the

1st observations $t^2=4\pi^2\frac{l}{g}$ ......(1)

For the second observations $t_1^2=4\pi^2\frac{l-x}{g}$ ......(2)

Dividing (1) by (2) $\frac{t^2}{t_1^2}=\frac{l}{l-x}$. $\therefore\ l=\frac{t^2 x}{t^2-t_1^2}$

We can get the value of l.

Repeat the observations five times by decreasing the length each time by nearly the same amount and calculate the value of l as given above.

Get the mean value of l from these five observations.

Record thus —

Radius of the bob=(1) (2) (3) (4) Mean=

Precautions. The same as in previous experiment.

No. of obs.	Length	Time for 20 vibrations			Time period	Inaccessible length $l=\frac{t^2x}{(t^2-t_1^2)}$
				Mean		
1.						
2.						
3.						
4.						

Exercise 1. Show that the period of a simple pendulum is affected by the amplitude but is independent of the mass of the bob.

Exercise 2. Find the time period of a pendulum 1000 cm. long. [**Hint**—Use the mean value of l/t^2. Let it be equal to K. $\frac{l}{t^2}=K$ or $t^2=\frac{l}{K}$

Or $t=\sqrt{\frac{l}{K}}$ from which t may be found for $l=1000$ cm.]

HEAT

CHAPTER XIII

MEASUREMENT OF TEMPERATURE

The word **temperature** means the degree of hotness of a body measured according to some arbitrarily chosen scale. This degree of hotness or coldness, we perceive by our senses. In summer we feel hot and in winter we feel cold. This feeling is sometimes obtained through our sense of touch but not always, as we feel the sun warm and under the shade of a tree, we feel cold. But our sense of heat is generally faulty and unreliable as it may vary from one person to another and depends on the previous condition of our bodies. Even if it were possible for us to distinguish which of the two bodies is hotter or colder than the other. it is still extremely difficult, or nearly impossible to say by how much one is hotter or colder than the other. It is, therefore, highly desirable to estimate temperature by some property of matter which varies continuously with hotness and which always remains the same at the same hotness. The property most commonly used in practice for the estimation of temperature or hotness in a body is the change in volume by heat of some liquid containad in a glass envelop, such as expansion of mercury in the ordinary mercurial thermometer.

Scales of Temperature.—In order to estimate the value of a physical quantity we require a standard or unit with which to measure it. It is well-known that under normal conditions of atmospheric pressure, pure ice melts, and distilled water boils, always at definite temperatures called the fixed points. The interval of hotness between these two fixed temperatures is taken to be our standard and this interval is conveniently divided in three different ways to give us a 'unit' for measuring temperatures. Every such unit is called a 'degree' and is written as 4^0 (four degrees).

The most common scales used are known as (1) Centigrade (2) Fahrenheit and (3) Reaumur. The value of each division or degree on these scales and those of the fixed points shall clearly be understood from the following table and Fig. 56.

Scale of Temperature	Melting point of ice	Boiling point of water	Interval in degrees	Relation
Centigrade	0^0	100^0	100	$1^0C = \frac{9^0}{5}$ F
				$1^0F^* = \frac{5^0}{9}$ C
Fahrenheit	32^0	212^0	180	
				$1^0C = \frac{4^0}{5}$ R
Reaumur	0^0	80^0	8	$1^0R = \frac{5^0}{4}$ C

If F, C, and R=readings of a temperature on the Fahrenheit, Centigrade and Reaumur scales, we have

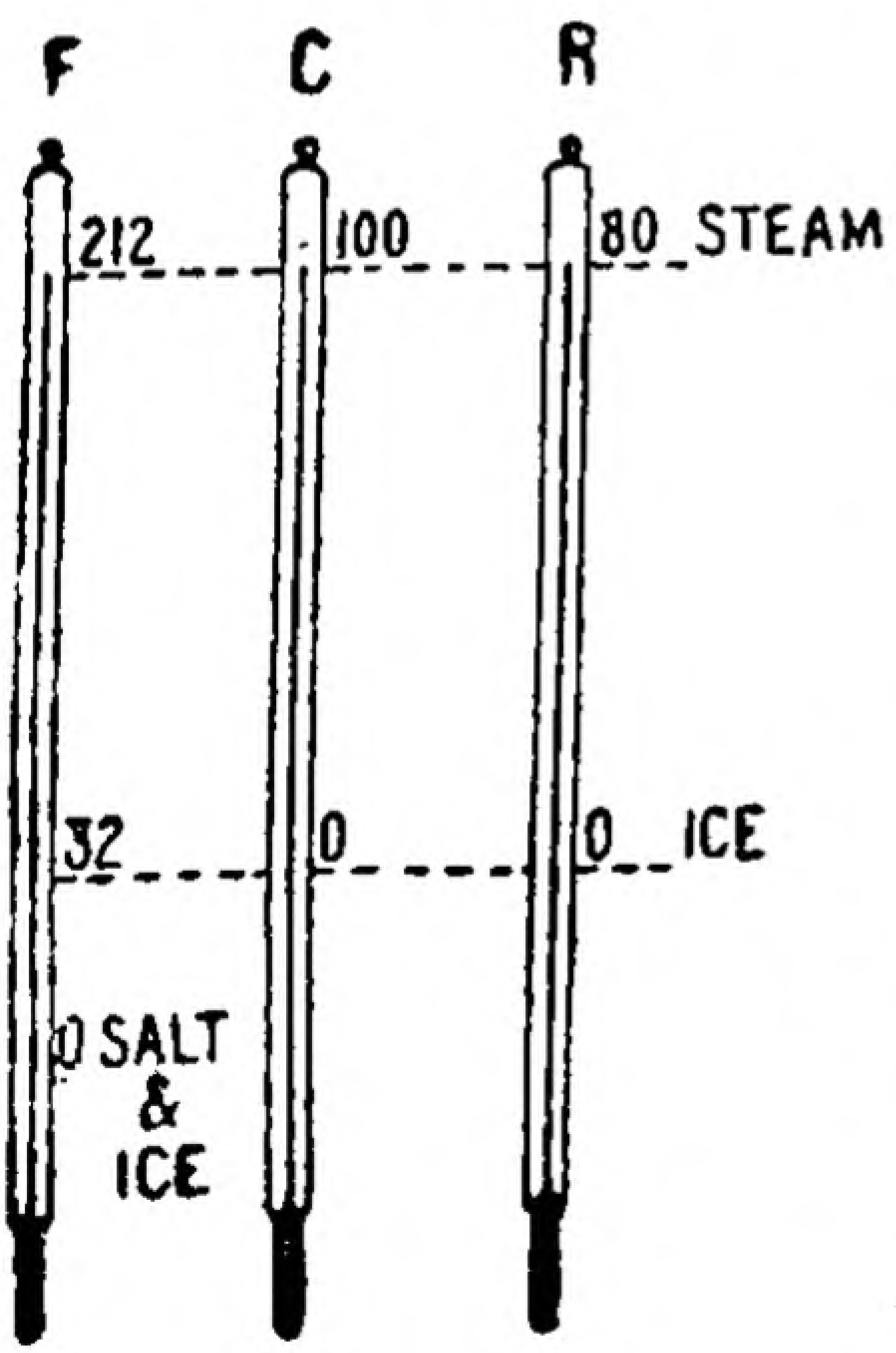


Fig. 56.

$$\frac{F\ 32}{180} = \frac{C}{100} = \frac{R}{80}$$

or $F = 1{\cdot}8C + 32 = 2{\cdot}25R + 32$ (1) which will be found to be a very useful relation for converting temperatures from one scale to another.

The Centigrade and the Fahrenheit scales are now very largely used in scientific work all the world over, while Reaumur is in use only in Germany and some other parts of Europe. As all experiments on heat require the use of the thermometers, we shall give below important directions for their use and taking readings.

**Note* — 1^0F here means one division on the Fahrenheit scale.

How to use and take readings on a thermometer.

1. Always hold the thermometer by the stem, in position, so that the mercury thread is clearly visible. Never hold it at the bulb for it is too frail to handle.

2. As far as possible keep the thermometer vertical.

3. The whole of the bulb and as much of the stem as possible should be in contact with the body whose tempera-trure is to be measured.

4. Never push the bulb of the thermometer into a solid broken into small pieces. When fixing it to a cork make the stem a little wet with water or glycerine, and push it on by rotating it in hand gently.

5. Never place it in contact with a very hot solid or plunge it into a hot liquid, whose temperature is more than what it can record, and allow it to get hot gradually or the bulb will break due to unequal heating.

6. Before using a thermometer, carefully note if it is graduated in Centigrade or Fahrenheit scale and the maximum and minimnm reading it can record.

7. Carefully note if it is divided in full or in half degrees. Every tenth or every fifth degree is indicated by a longer mark and is shown by a number.

8. While taking a reading keep the level of your eyes the same as the level of mercury in the stem, to avoid error of "Parallax."

9. Estimate the fifths of a degree, by eye-sight and take readings quickly in cases where temperature is rapidly changing.

10. Be careful to keep the thermometer in case when not is use, introducing it into the case gently by tilting the case, so as to avoid breaking the bulb.

11. Always be sure that the bulb of the thermometer is intact before use.

12. As far as possible avoid holding the thermometer in hand ; always clamp it in a soft pad of cork or even of paper.

Experiment 43.—**To draw a graph showing the relation between the readings on Centigrade and Fahrenheit scales.**

Apparatus:—A Centigrade and a Fahrenheit thermometer, a few rubber bands, a beaker with stirrer, a retort stand with clamps and a piece of wire gauze, and a gas burner.

Method and Manipulations :—Half fill the beaker with water and place it on the wire gauze. Fasten the two thermometers with rubber bands so that the bulbs are side by side. Clamp or suspend them on the clamp by a piece of thread and so adjust the clamp that the bulbs are well under water. Heat water to boiling and note the highest temperature on both the scales. Remove the burner and allow water to cool, taking readings after a fall of about 10^0 on the centigrade scale. Every time stir the water well before taking a reading. If the cooling be slow add some cold water, stir well and take a reading. For readings below the room temperature, pieces of ice are also added. In this way some ten readings are taken and recorded as in the table given below :—

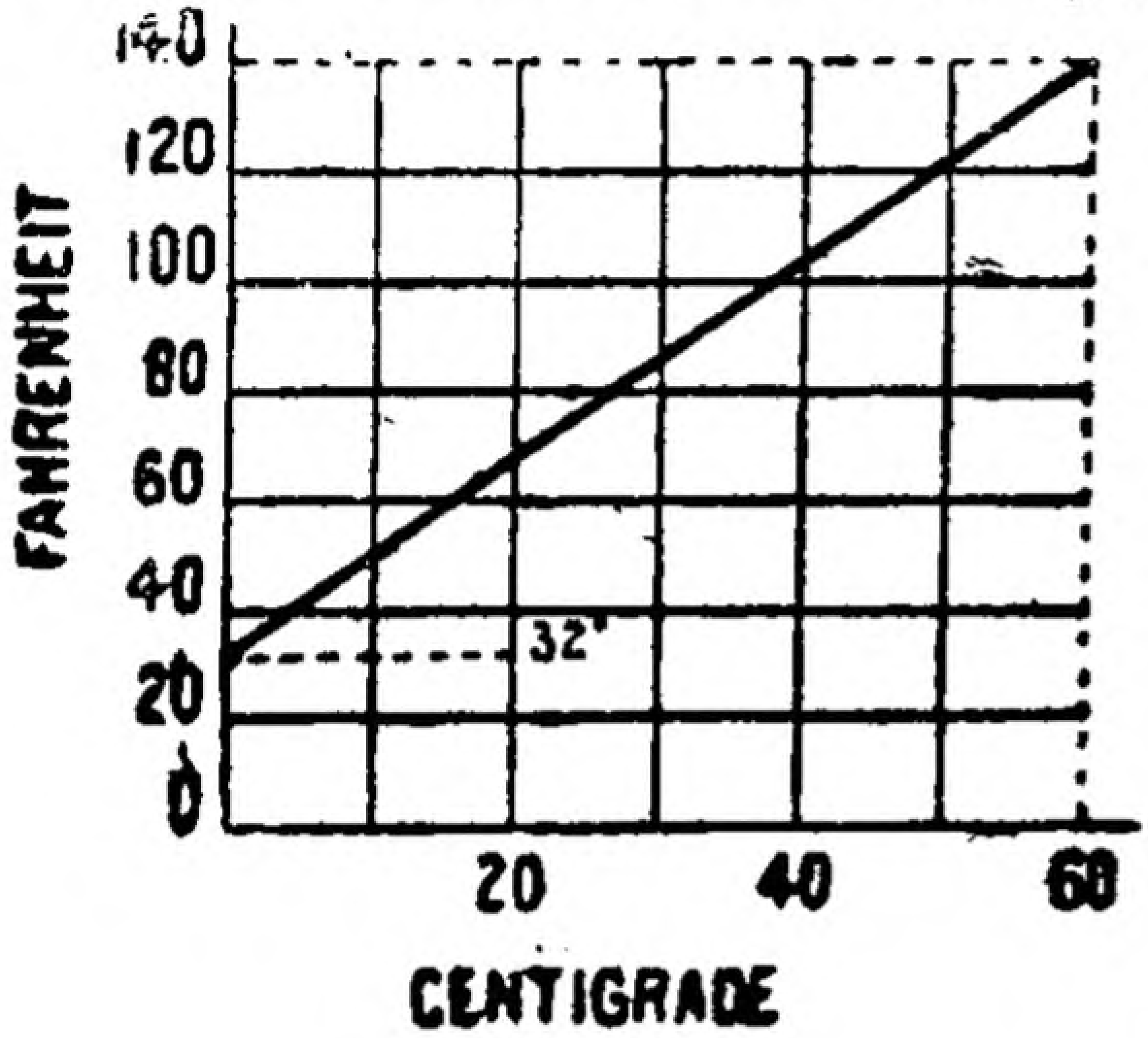


Fig. 57.

The graph is plotted as shown in Fig. 57.

Observations :

1	2	3	4	5	6	7	8	9	10	
Centigrade										degrees (^0C)
Fahrenheit										degrees (^0F)
Fahrenheit (Calculated)										degrees (^0F)

Calculations and Result :—

$$\frac{F-32}{C}=\frac{140-32}{60}=1\cdot 8$$

or $F=1\cdot 8C+32$. ...(1)

If

$$\left.\begin{array}{l} F=y \\ C=x \end{array}\right| \begin{array}{l} 1\cdot 8=m \\ 32=c \end{array} \left| \begin{array}{l} \text{we get} \\ y=mx+c \end{array}\right.$$

which is the equation of a straight line.

Precautions :—

1. The bulbs should be well under water and should be side by side.

2. Water should be well-stirred before taking a reading.

3. Eyes should be in level with the mercury thread while taking a reading.

4. Readings should be taken to tenths of a degree on both thermometers nearly simultaneously.

With suitable units, and the zero of both scales as origin plot the Centigrade readings along axis of X and the Fahrenheit readings along the axis of Y. The points plotted will be found to lie on a straight line as shown in the graph

If F=reading on the Fahrenheit, and C=reading on the Centigrade scale, the inclination of the graph to the abscissa will have its tangent

$$m=\frac{F-32}{C}=\frac{140-32}{60}=1\cdot 8.$$

The intercept made by the graph on the ordinate, $c=32$.

The equation of a straight line is

$$y=mx+c \left| \begin{array}{l} \text{where} \\ m=\text{tangent of the angle made with X-axis.} \\ c=\text{intercept made on Y-axis} \end{array}\right.$$

Substituting F for y, and C for x and putting $m=1\cdot 8$ and $c=32$, we get

$$F=1\cdot 8C+32,$$

the relation already obtained in equation (1).

The graph has thus been intercepted in the form of an equation of a law connecting the readings on the two scales of temperature. From the graph we can also determine the value of a Centigrade reading in terms of the Fahrenheit scale. The position of the various points plotted with respect to the graph clearly shows the accuracy of the observations taken.

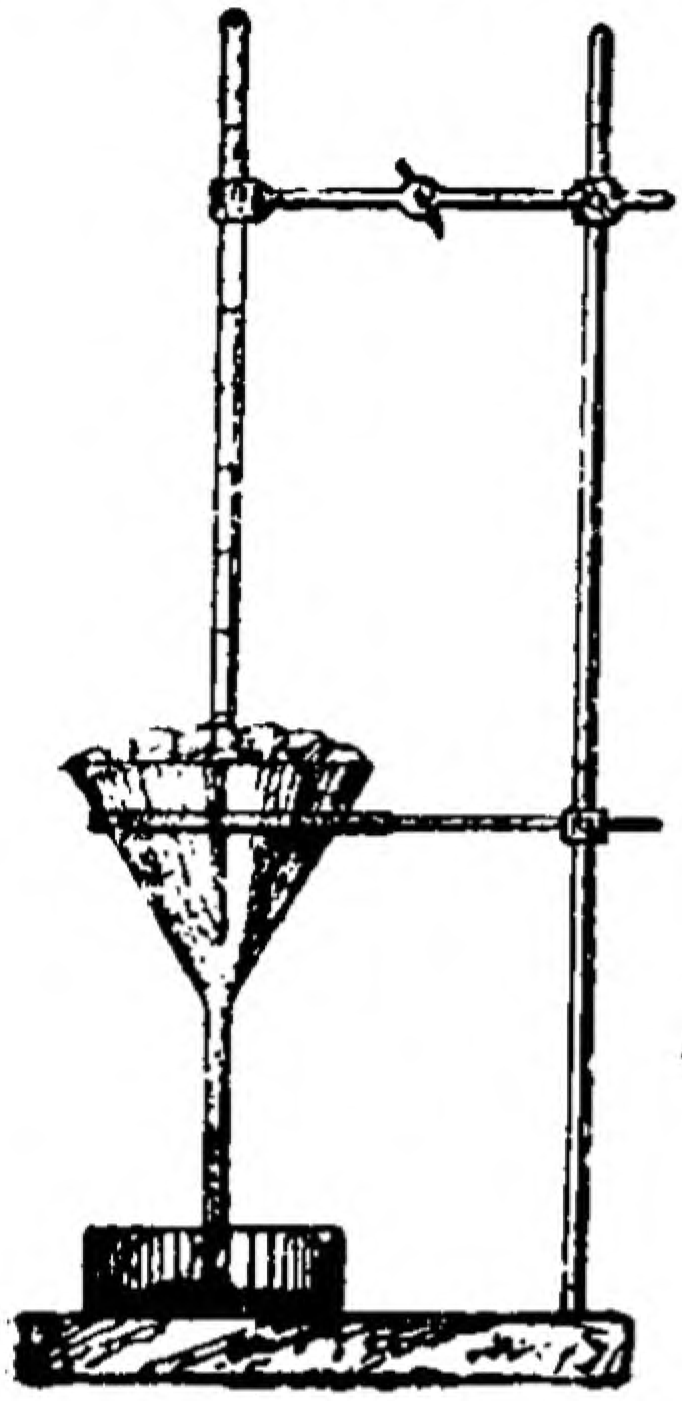


Fig. 58.

Experiment 44.—**To test the accuracy of the lower fixed point or the melting point of ice, on the centigrade thermometer.**

Apparatus :—A thermometer, a wide funnel on a stand, with clamp for holding the thermometer, and a receptacle to receive water from melting ice.

Method and Manipulations :—Wash ice with distilled water and break it to pieces by a hammer. Fill the funnel with pounded ice and adjust its height so that the water trickling down does not spill.

Make a hole in the ice, at the centre of the funnel with a pencil to receive the bulb of the thermometer. Adjust the height of the thermometer, so that its bulb is well-surrounded by ice, and its zero mark is just visible above it. Take the readings of temperature after intervals of about 1 mt. each. The lowest reading which remains constant for some time is the zero reading.

Record your observations thus :

Observations :

No. of Observations.	1	2	3	4	5	6	7	8	9	10	Lowest observed (constant)
Readings of temperature.											

Zero Reading		Erorr (1) - (2)	Correction (—Error)
Observed (1)	Actual (2)		
—1·0°C	0·0°C	—1·0°C	1·0°C

Calculations and Results :

Error—1·0°C, correction + 1·0°C.

Precautions :

1. Thermometer fixed vertically, bulb in contact with ice.
2. Eyes kept in level with mercury column.
3. Ice washed to avoid soluble impurities sticking to the surface.
4. Lowest reading, remaining constant for some time, observed.
5. Reading taken to one fifth of a degree.

Experiment 45.—**To test the accuracy of the upper fixed point, boiling point of distilled water on a centigrade thermometer**

Apparatus.—A thermometer, an hypsometer on a tripod stand, a beaker to receive condensed steam on a block of wood, and a Bunsen burner.

Method and **Manipulations.**—Fill nearly three-quarters of the hypsometer with water, place it on the tripod stand. Fix the thermometer in the cork so that the mark 98°C, or thereabouts, is just above it. Fit the cork to the hypsometer cover. Fill the manometric (U) tube with some coloured water. Place the cover in position and begin heating the water in the hypsometer as shown in Fig. 59. In the meanwhile note the temperature of the room and read the height of the

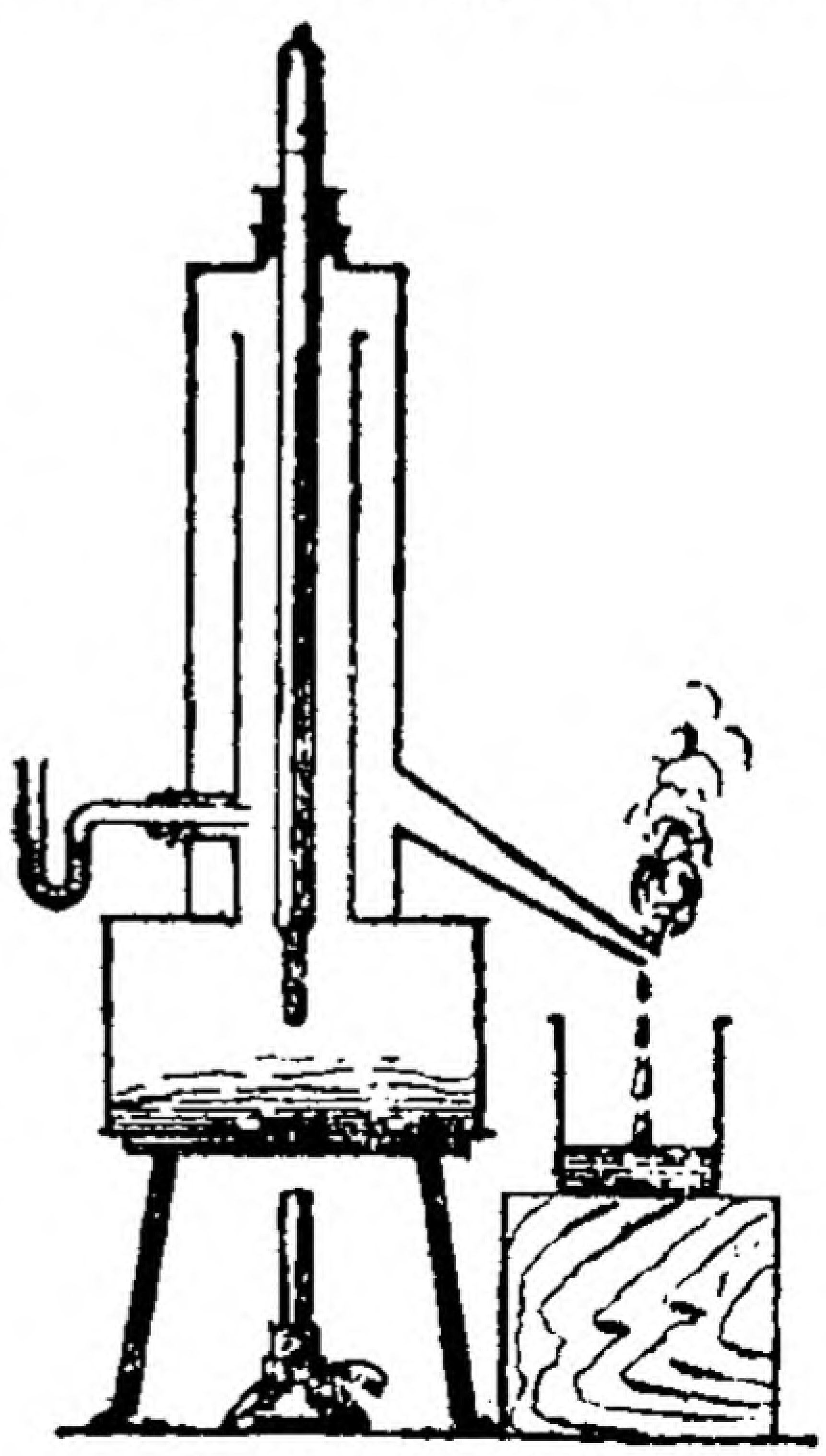


Fig. 59.

barometer. The temperature at first rises quickly then slowly and after some time becomes stationary when the water begins to boil. Note this temperature at least five times after intervals of about one minute, and record as follows :—

Observations : Temperature of the room=°C. Barometer= m.m.

No. of Observation	1	2	3	4	5	Boiling Point (observed)
Readings of Temperature						

Boiling Point		Error	Correction
Observed 1	Calculated 2	1—2	—(Error)

Calculations and Results.—The barometric height being corrected for temperature etc., the boiling point of water is calculated from it thus ; charge of 1 m. m. in barometric height, changes the B.P. by 0·036°C.

Calculated B. P.$=100\pm$(correct pressure$-760)\times{\cdot}036$.

B.P. (corrected) =B.P. (observed)$\pm$ correction.

Precautions : Same as in experiment 44. The bulb of the thermometer is never placed in water, but in steam. The B. P. of tap water is always higher than that of water free from soluble impurities.

Note.—Changes in atmospheric pressure produce no appreciable change in the melting point of ice, but they

affect the boiling point of water appreciably. If the pressure of steam insidse rises above the atmospheric pressure outside, water level in the open limb of the manometric tube will rise. To avoid or diminish this difference of pressure the burner is let down, so that water does not boil as rapidly as before.

Exercise—From the freezing and boiling point corrections of a thermometer plot a graph for corrections of temperatures lying between 0^0 and 100^0C.

Let freezing point correction be$=-10^0$C.

and boiling point correction be$=+1{\cdot}3^0$C.

If the bore of the thermometric tube be taken to be uniform, the corrections for temperatures lying between

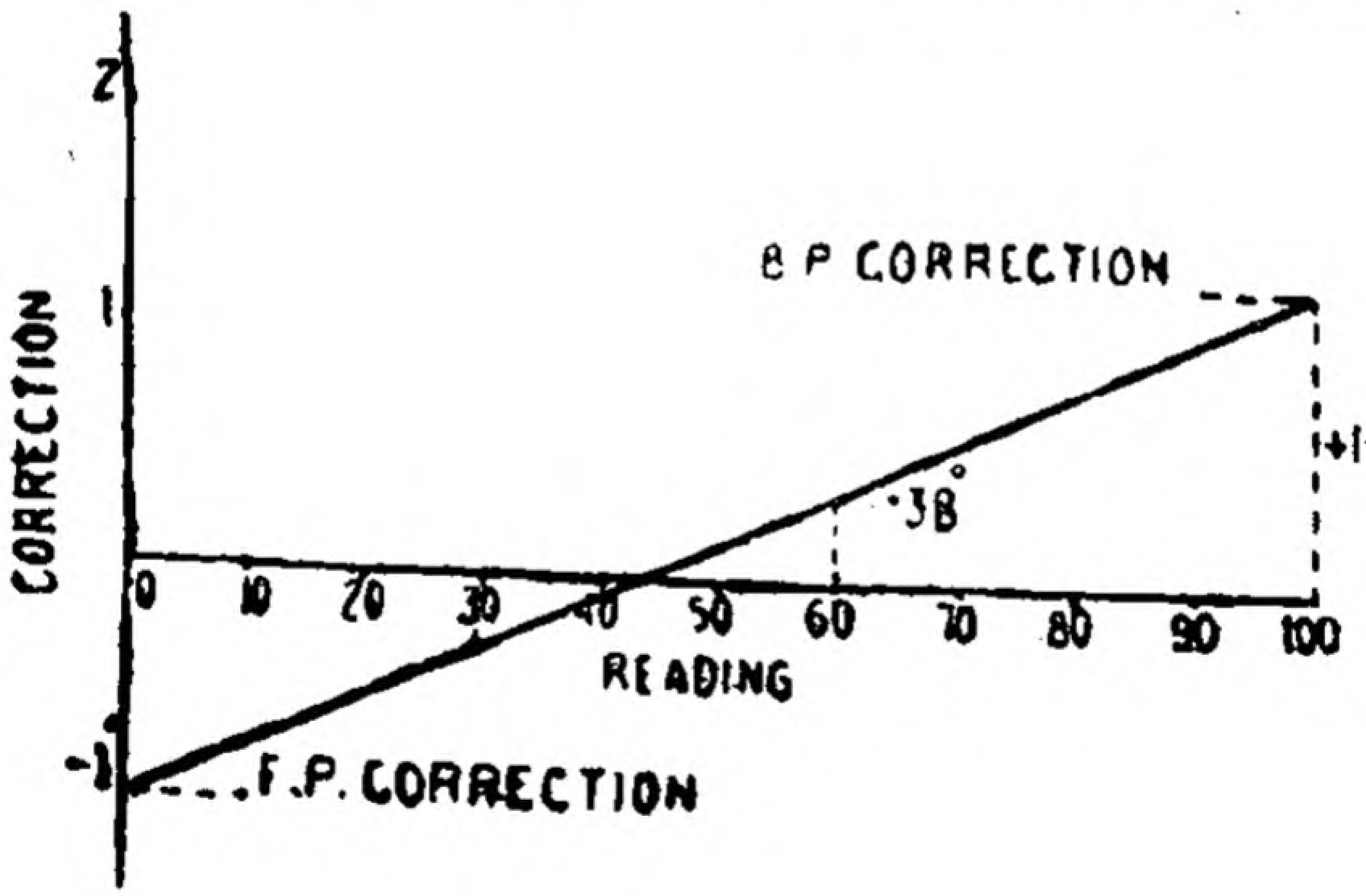


Fig. 60.

0·0° and ·100·0°C will gradually rise from 1·0°C to +1·3°C. With suitable scales plot the temperatures as abscissae and corrections as ordinates as shown in the figure (Fig. 60.) plot corrections for 0°C and 100·0°C and join these by a straight line. It will be obvious that this cuts the X-axis at 45°C, *i.e.*, the correction at this temperature is zero. It is $-t$ degrees below this temperature and $+t$ degrees above it. At 60°C it is$+0{\cdot}38$°C.

CHAPTER XIV

CHANGE OF STATE

Fusion or Melting. Almost all solids fuse or liquefy at definite temperatures, and on cooling resolidify at nearly the same temperature (point of liquefaction). This temperature is known as the melting point or point of liquefaction of the solid or freezing point of solidification of the liquid. Those which solidify at points below the ordinary temperatures, as water, are in common language said to 'freeze' while those changing their state at high temperatures are said to solidify. This change of state, under general physical conditions, and under circumstances in which solids do not change in melting takes place abruptly at definitely fixed temperature, which does not change so long as the change is taking place and is not complete. The pressure effects this temperature but not to an appreciable extent. During the time the change of state from solid to liquid or *vice versa* from liquid to solid is taking place, the substance gains or loses heat from or to its surroundings, known as its Latent Heat and its temperature remains constant.

The melting point is either determined directly by noting the temperature at which a little of the solid placed in a thin capillary tube, melts or solidifies or indirectly by the method of cooling, in which the temperature at which a molten solid changes its state, and which remains constant during the loss of its latent heat, is observed.

Experiment 46. **To determine the melting point of a solid (naphthalene) by the capillary tube.**

Apparatus.—A thermometer, glass tubing, rubber bands, small beaker with stirrer, a retort stand with clamp, tripod stand with wire gauze, a fish-tail burner and an ordinary Bunsen burner.

Method and Manipulations.—With the help of the fishtail burner the tube is drawn out at the middle, and broken into two, so as to form two capillary tubes with open ends. Some molten wax is sucked into one of them through the finer end, which is then sealed in the hottest part of the flame. If the solid be in the form of a powder, it is shaken into the tube from the wider end and with the help of rubber bands the tube is stuck to the thermometer so that the capillary end is near its bulb. The beaker is three fourth filled with water and placed on the tripod stand. The thermometer with the tube attached to it is so adjusted as to have its bulb well under water. (It is always advisable to perform a preliminary experiment to ascertain approximately the melting point). Water is slowly heated, until the temperature is a few degrees below the m. pt. and then more slowly all the while stirring the water. The temperature, at which the solid just begins to melt is noted carefully.

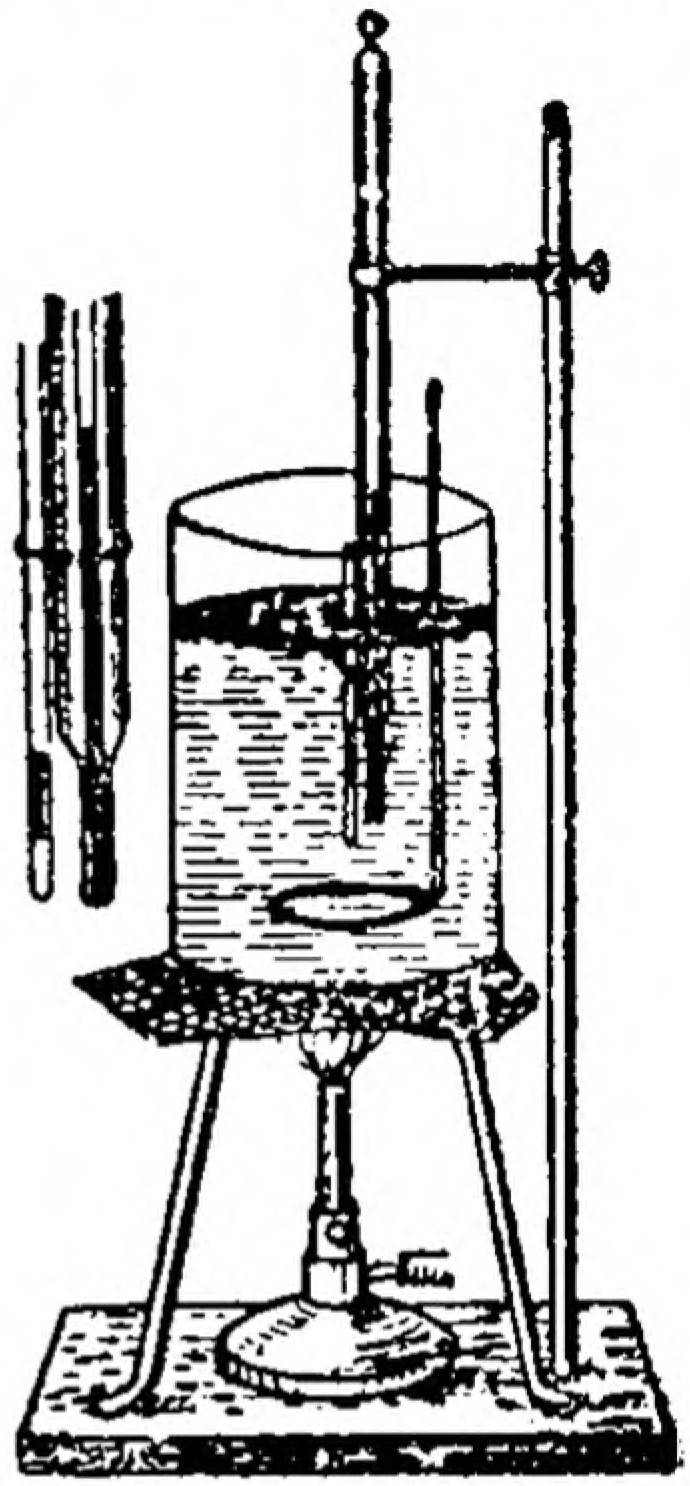


Fig. 61.

This will be the case when the solid begins to appear transparent. The flame is then put out and the liquified solid allowed to cool. Its temperature is again noted when it begins to solidify. This will occur when the liquid appears to be hazy. This is repeated several times and the mean of all the observations is taken.

Observations :

No. of Observations.	Temperature (1) Liquefaction	Temperature (2) Solidification	Mean Melting point
	°C	°C	°C
(1)			
(2)			
(3)			

Mean= °C

Calculations and Result.—

Melting point$=\ldots{}^{0}$C.

Precautions :

1. Readings in column (1) are generally higher and those in column (2) are lower than the actual value, hence mean of the two eliminates this error.

2. The water bath is well stirred specially before taking the reading.

3. Temperature is noted just when the melting or solidification starts.

4. Temperature is read to the first place of decimal.

5. Water is heated slowly near the melting point.

NOTE (1).—For some organic solids, or substances like sulphur, which change slightly on liquifaction, only the temperature at which they melt is noted.

(2) For solids whose m. pt. is higher than the boiling point of water, castor oil or sulphuric acid is used ; while those which are liquid at ordinary temperatures are cooled with the help of ice.

(3) Substances that are generally opaque when solids become translucent or even transparent on liquifaction, in which cases, change of state is easily detected. But this change is not quite obvious as in the case of wax, in which needle-shaped lines like white threads are visible when solidification starts ; while in others change from the liquid into solid state is marked by the disappearance of the meniscus.

(4) In some cases, over-heating or over-cooling takes place, specially the latter, without any visible sign of melting or solidification. This sets in, however, immediately the solid or liquid is shaken by tapping the tube.

Experiment 47.—**To determine the melting point of a solid (wax) by the cooling curve method.**

Apparatus.—A thermometer, a boiling tube with stirrer, a small beaker, stand with thermometer clamp, a ring with wire-gauze, a Bunsen burner and a watch with seconds hand.

Method.—Fit up the apparatus as shown in the figure. Put sufficient solid into the tube to cover the bulb and some portion of the stem of the thermometer. Fill the beaker with water, so that the portion of the tube containing the solid is well within water. Continue heating the beaker until the whole of the solid in the tube is melted. Remove the burner and allow the liquid to cool slowly and steadily, noting the temperatures after stirring well, after intervals of half minute. When the cooling becomes slower this may be increased to one minute or even two minutes. The temperature will in the beginning, fall steadily but for some time will remain stationary or nearly so and will then begin to fall less rapidly. Continue stirring all the time that the readings are being taken even after the solid has solidified and stop after taking some readings in the solid state. Record observations and plot a graph with time as abscissæ and temperatures as ordinates. The flat part of the curve shows that although heat was continuously lost by the substance at this stage, yet its temperature remained practically steady. This will be the melting point of the solid.

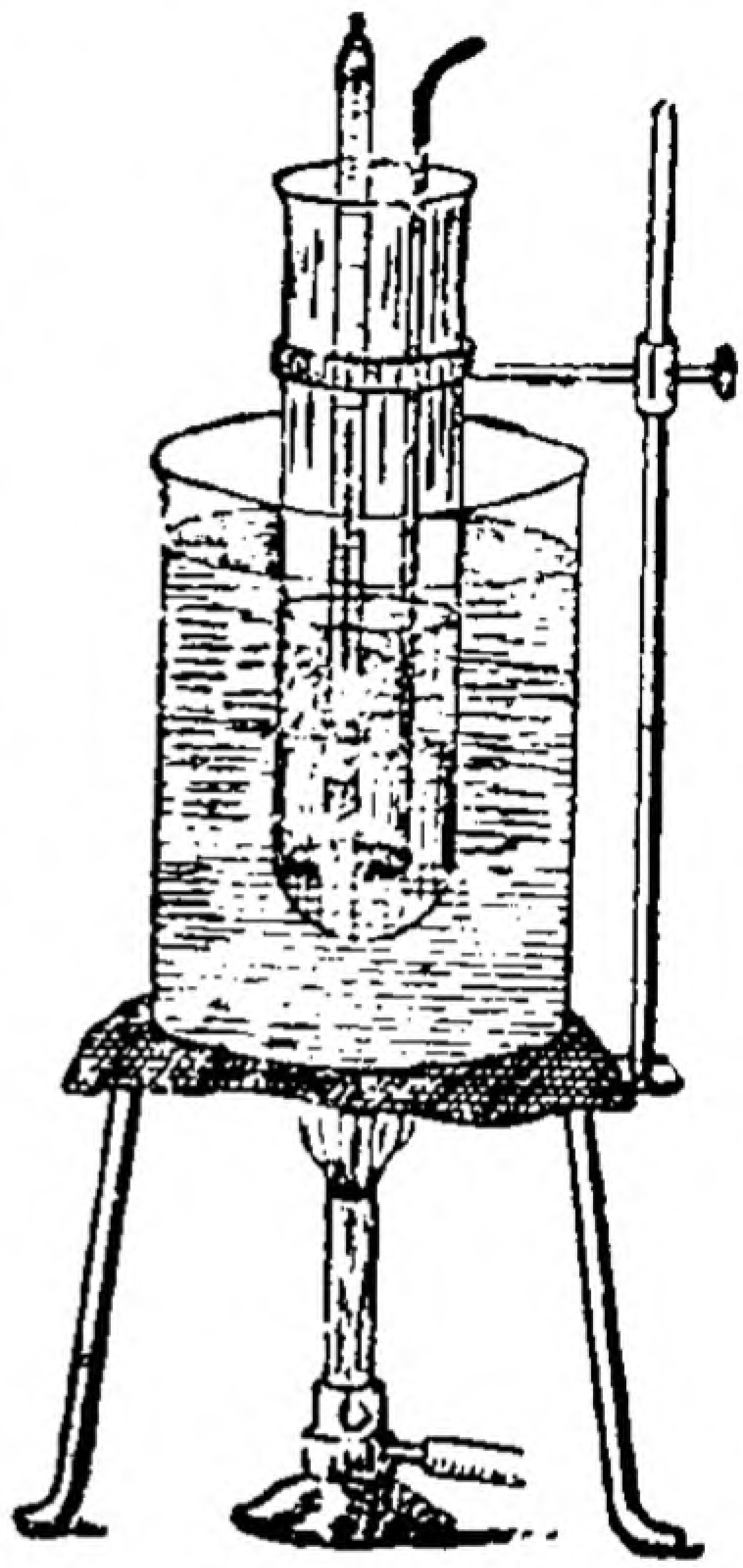


Fig. 62.

Observations :—

No. of Obs.	1	2	3	4	5	6	7	8	9	
Time.										Mts
Temperature.										^0C

Calculations and Results.—Melting point of the solid $=58{\cdot}0^0C$ nearly.

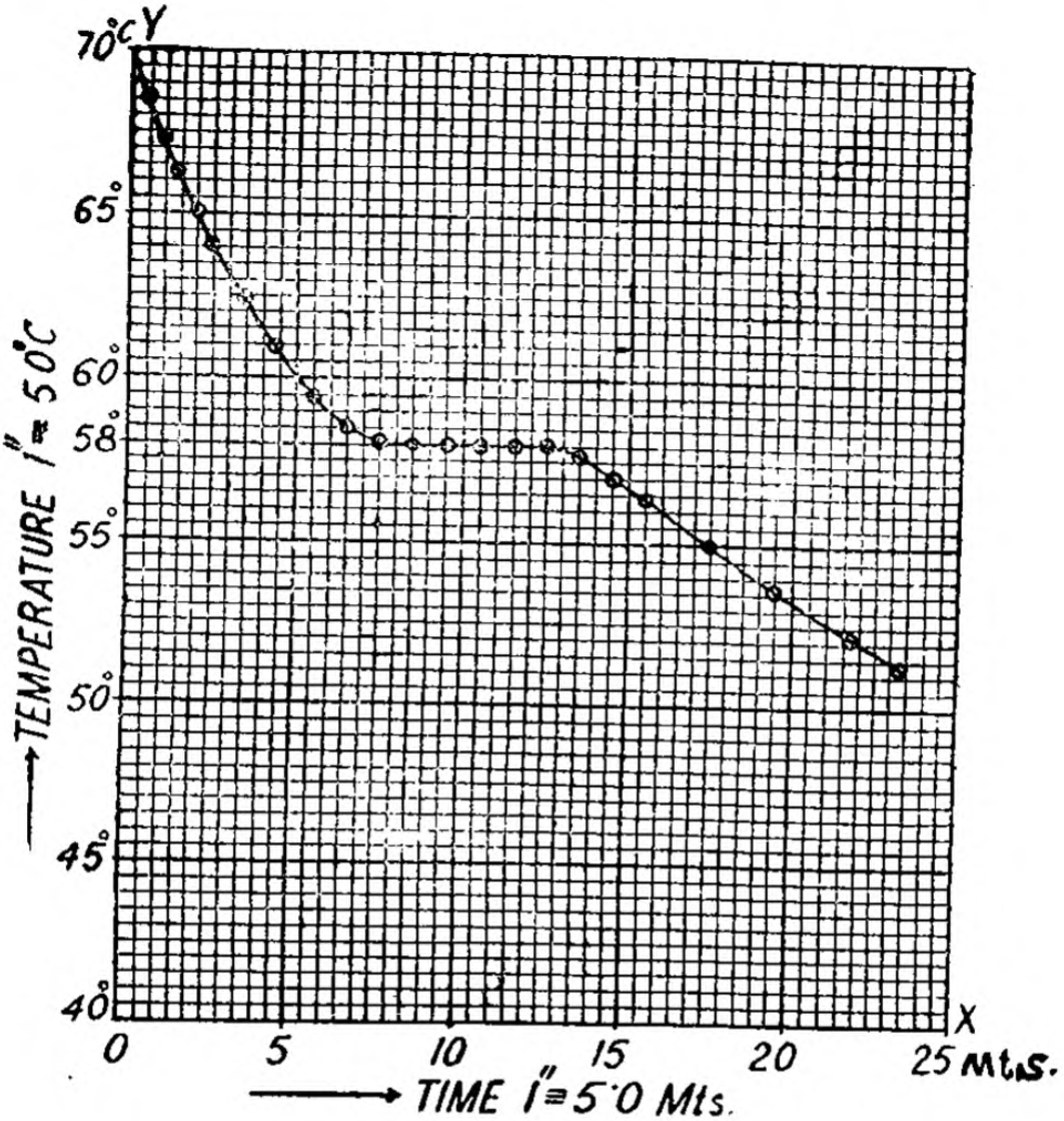


Fig. 63.

Precautions :1. The quantity of water in the beaker is so adjusted that the cooling is neither too rapid nor too slow.

2. The liquid is kept well stirred specially before taking a reading.

3. Eyes are kept in level with the mercury end, and readings are taken to fifth of a degree.

4. While heating the solid an approximate reading of its melting point is taken and its temperature is not allowed to rise too much above it.

5. Readings are taken quickly.

Note.—This method is applicable with advantage to solids which are not opaque in the solid state or which pass through a plastic semi-solid state before solidification, like wax, butter, etc.

Evaporation and Ebullition.—Evaporation is comparatively slower process of conversion of a liquid into vapour which takes place only at the surface, and at all temperatures, while ebullition is the more rapid process in which liquid changes into vapour vigorously with the evolution of bubbles throughout the liquid, and under definite conditions of pressure, take place only at fixed temperature. This temperature at which a liquid boils at Normal Pressure is called its *Boiling Point* and it remains constant so long as the whole of the liquid is not boiled off. During this transition the heat absorbed by the liquid is not detected by the thermometer and is wholly used in changing its state and is called its *Latent Heat of Vaporisation*. The greater the pressure, the higher the boiling point.

Due to a large amount of evaporation throughout the year, there is always some moisture present in the atmosphere. This exerts a definite pressure called the *Vapour Pressure* which depends upon the amount of vapour present. When the air is so rich in moisture that it cannot hold or absorb any more, it is said to be *saturated*. The pressure which the vapour then exerts is called the *Maximum Vapour Pressure*. This maximum pressure increases with rise of temperature.

The maximum vapour pressure of a liquid at its boiling point is always equal to the pressure at which the boiling takes place. The boiling point of a liquid can, therefore, be determined, by a method by which we can find its vapour pressure at different temperatures. We describe one such method below:—

Experiment 48. (*a*)—**To determine the boiling point of a liquid directly, at the ordinary atmospheric pressure.**

NOTE.—We have already described the method of determining the boiling point of water (pure) under Experiment 44. We shall give below the special features of a method to determine the boiling point of an inflammable liquid, or of a solution of a solid in water.

Same apparatus is used as in experiment 48 with this difference that the hypsometer is replaced by a boiling tube or a glass flask. The apparatus is fitted up as in figure 64. The boiling tube is fitted with a straight outlet tube, to keep the vapours of the inflammable liquid away from the flame and to get the condensed vapour back into the boiler. To heat the liquid slowly and steadily a sand bath is used.

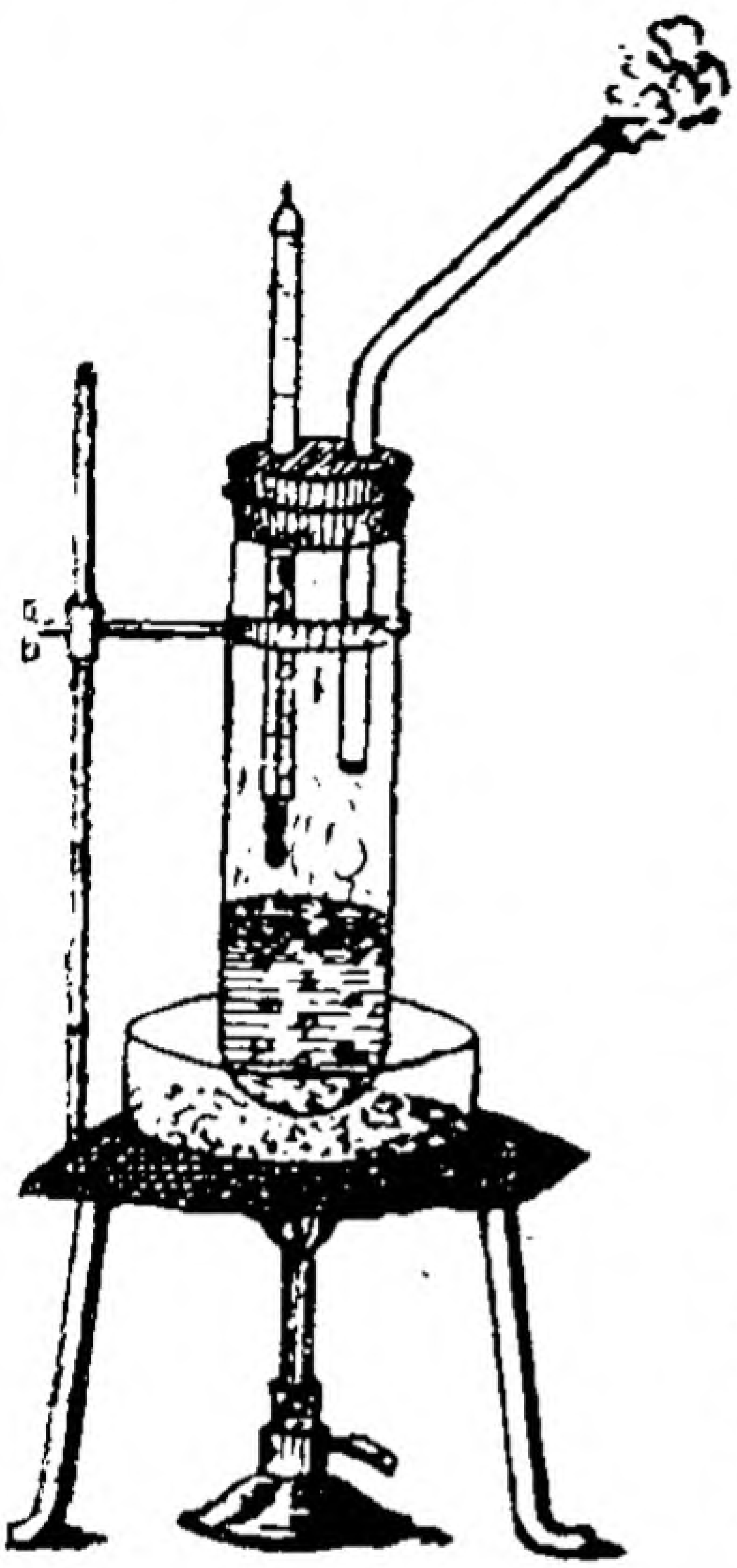


Fig. 64.

To avoid bumping (splashing with noise) small pieces of broken glass tubing are generally placed at the bottom of the liquid.

To determine the boiling point of pure liquid, the bulb of the thermometer is placed in the vapour above the surface of the liquid, while in case of solutions or mixture of liquids it is put under the surface of the liquid.

Experiment 48 (b).—**To determine the boiling point of a liquid by the method of Vapour Pressures.**

Apparatus.—A bent J tube, with its shorter limb closed, mercury, thermometer, a steel scale, a wide beaker with stirrer, a retort stand with clamps, wire gauze and a burner.

Method.—Fill the tube with mercury so that there is no air gap left between the mercury surface and the closed end. By tilting the tube introduce a little of the liquid above mercury at this end. Fit the tube in a vertical position with the steel scale in between the two limbs as shown in figure 65. Fill the beaker with water so as to dip the closed end with the liquid in it. Place the beaker on the stand and begin heating the water slowly. The mercury level in the shorter limb will descend and will rise in the longer one. Remove the burner when the level is nearly the same in

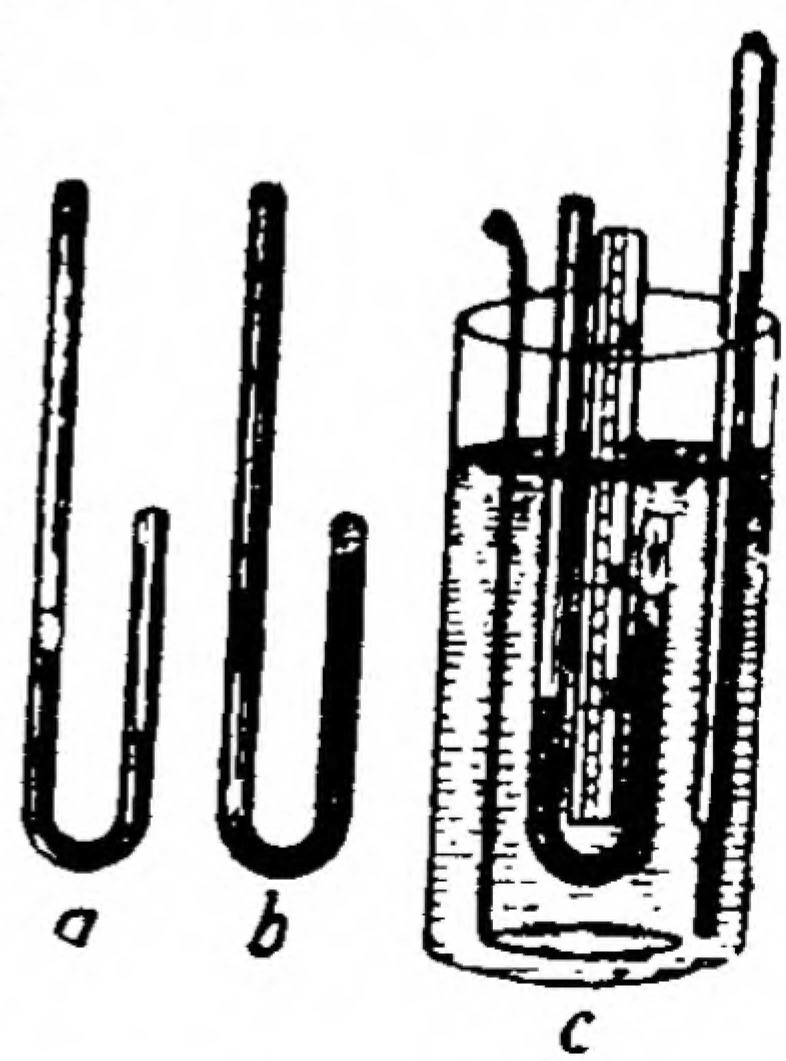


Fig. 65.

both. Stir the bath well and read the temperature of the bath when the level is the same.

The level of mercury will continue to descend for some time, but will rise again when the water in the beaker begins to cool. Another reading is taken when the level is again the same, and this is repeated several times. The mean of these readings gives the boiling point of the liquid. Record observations thus :

Observations :

No. of Observations.	Boiling Point		Mean B. Pt.
	Temperature rising	Temperature falling	
(1)			
(2)			
(3)			

Result :
Boiling point=...°C.

Precautions : 1. The water is well stirred before the temperature is read.

2. To avoid parallax error, readings are taken by keeping the eye in the same level as the mercury, both in the tube and thermometer.

3. Heating and cooling of the bath should be slow.

4. Sufficient liquid is introduced into the tube to ensure its presence even after evaporation.

NOTE.—The same apparatus can be used to determine the vapour pressure of a liquid at different temperatures. The difference in the level of mercury in the two limbs subtracted from or added to the barometric reading, gives the pressure, while the reading of the thermometer the corresponding temperature.

By a series of experiments tables of maximum vapour pressure of liquids at different temperatures have been prepared and may be usefully consulted to determine the boiling point of a liquid by taking the reading of the baro

meter. Or graphs may be drawn showing vapour pressure against temperatures, and boiling points at the atmospheric pressure or any other pressure are determined from it. Such tables are also prepared for water vapour and their use is explained further in this chapter.

Relative Humidity and Dew Point.—The amount of water vapour present in the atmosphere is different at different times during the day or night, in different seasons during the year, and in different localities. During a hot summer day this amount is less and the weather is dry while in the rainy season it is more and the air at any temperature is not always the maximum it can hold at that temperature. At any definite temperature, the pressure exerted by aqueous vapour is always proportional to the amount present in a given volume of air. The ratio of the amount actually present in the air at any temperature to the maximum required to saturate it at the same temperature is called **Relative Humidity** or the **Humidity** of the air. Or, as at constant temperature vapour pressures are proportional to the quantity of vapour present, we can write Relative Humidity.

$$= \frac{\text{Actual vapour pressure.}}{\text{Maximum vapour pressure}}$$

The study of the amount of water present in the air at any time or place, is called **Hygrometry** and the apparatus used to determine it is known as **Hygrometer**.

When the air is gradually cooled, a temperature is reached at which the amount of water vapour actually present in the atmosphere becomes the maximum that it can hold at that temperature and the vapour begins to condense on colder bodies in the form of small drops of water. This temperature is called the *Dew point*. The actual vapour pressure at any temperature becomes the maximum at the *Dew point*. Various Hygrometers are devised on this principle. The dew point or temperature at which the vapour begins to condense on a shining metal surface is determined directly and the maximum vapour pressure at this temperature is ascertained from the tables. This gives the actual vapour pressure at the temperature at which the experiment is performed. The maximum vapour pres-

sure at this temperature is also known similarly, and the Relative Humidity is then found thus :

$$\text{Relative Humidity} = \frac{\text{Max. vapour press. at Dew Point}}{\text{Max. vapour press. at room temp.}}$$

The Relative Humidity is generally expressed as a percentage by multiplying the ratio in decimal fractions by 100.

Wet and Dry Bulb Hygrometer.—This consists of two centigrade thermometers fixed side by side, vertically on a stand, as shown in figure 66. One of the bulbs is covered by a wet muslin cloth or a wick, the other end of which dips under water provided in a cup fixed below the thermometer. This is called the wet bulb and the other the dry bulb.

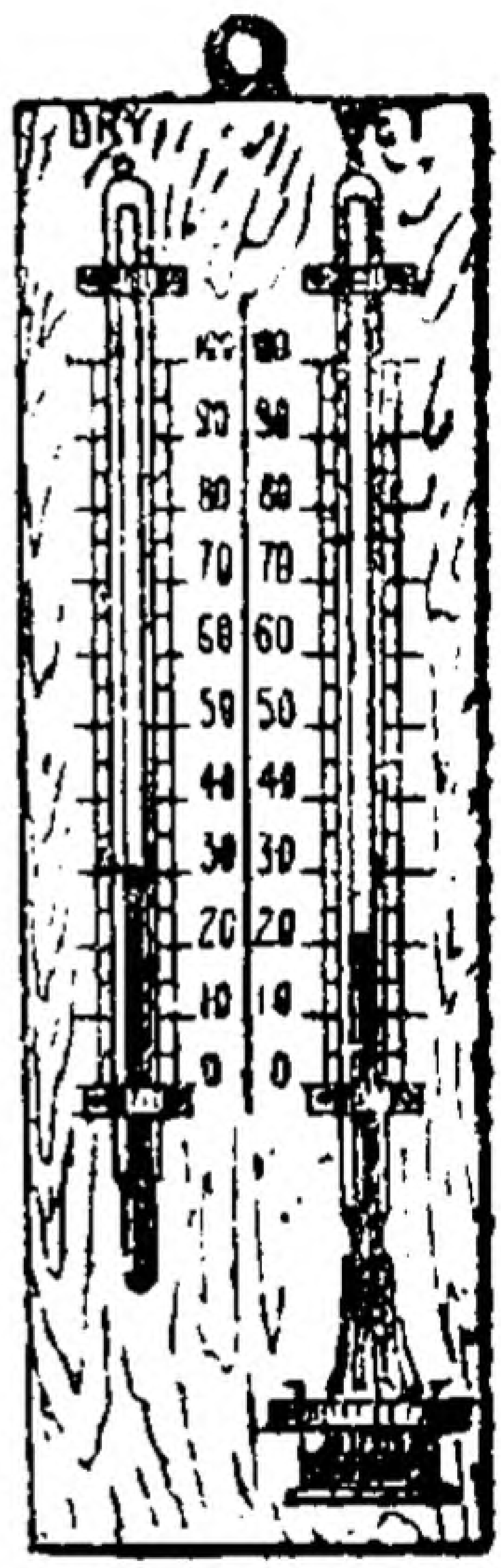


Fig. 66.

Such an hygrometer can conveniently be made by the student by taking two centigrade thermometers, suspending them from a retort stand and covering the bulbs of one of them by a thin, wet muslin cloth, the other end of which is dipping in water in a small beaker.

As evaporation of water progresses on the surface of the wet bulb, the latent heat of vaporisation is absorbed mainly from the bulb and temperature is gradually lowered. The amount of evaporation taking place depends upon the quantity of water vapour present at the time in the surrounding air. The lowering of the temperature of the wet bulb is, therefore, a measure of the dampness of the air. The relation between the cooling produced and the humidity of air is, however, known. The reading of the dry bulb and the lowest reading of the wet bulb are noted and the difference of the first and the second recorded.

The Relative Humidity of the air and the Dew Point are determined from the tables of vapour pressures thus.

How to consult the Vapour Pressure Tables :—The temperatures given are in Centigrade scale and the pressures in inches of mercury. The first column gives the temperature of the wet bulb. The difierence columns marked 0, 1, 2, 3 etc. to 14, give the values of the actual vapour pressures, for a particular difference of the dry and wet bulb readings. When the air is saturated with vapour at any temperature, it cannot hold any more of it, there is no evaporation at the surface of the wet bulb, and the reading of the wet bulb does not fall below that of the dry bulb. The pressures given against any temperature in the first column and under the difference column marked zero are, therefore, maximum vapour pressures. The pressures will in this case, be either for the wet or dry bulb temperatures. The ratio of the actual and the maximum vapour pressure at the room temperature gives the Relative Humidity. The actual vapour pressure as determined above is found in the column under zero, and the temperature against this in the first column gives the temperature at which this is maximum : this is the Dew-point.

Experiment 49.—**To determine the Relative Humidity and the Dew point of the air by means of the wet and dry bulb hygrometer.**

Apparatus.—Two Centigrade thermometers, a piece of muslin cloth, a piece of thread, a beaker and a stand.

Method.—The thermometers are suspended from the stand by means of the thread. The cloth is tied to one of the bulbs, is soaked in water and its lower end is left dipping in water in the beaker. The readings on the two thermometers are taken after intervals of one minute and recorded as given on the next page. The mean of the dry-bulb readings gives the room temperature and the lowest reading on the wet-bulb is taken as the wet-bulb reading.

No. of Obs.	1	2	3	4	5	6	7	8	9	10	
	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	
Dry-bulb											Mean = . . °C
Wet-bulb											Wet = . . °C

Observation :—

Calculations and Results :

(1) Actual vapour pressure from tables= inches

(2) Maximum vapour pressure at room tem. from tables=

$$\text{Relative Humidity} = \frac{(1)}{(2)} \times 100\%$$

The dew-point from tables=...°C.

Precautions : 1. If the cloth be greasy, it should be cleaned by washing in caustic soda solution and rinsing in water.

2. The wet bulb of the thermometer should not dip in water.

3. The two bulbs should be kept apart to avoid the evaporation affecting the dry-bulb readings.

4. Parallax error is avoided while taking the readings and temperatures are read to tenths or fifths of a degree.

5. The atmosphere should be calm and a draught should be avoided. The observer should hold his breath while taking readings.

The tables, however, do not give figures for some temperatures and for fractions. These are determined by proportional parts which we shall now explain below.

How to consult tables for Proportional Parts .

Let us say the following are the observations in an experiment :

(1) Dry-bulb reading $=25{\cdot}0^{0}C$.

(2) Wet-bulb reading $=14{\cdot}5^{0}C$.

(3) Difference ,, $=10{\cdot}5^{0}C$.

Determine the Relative Humidity and the dew point.

From the tables we have :

Wet bulb Reading	Difference between Dry and Wet-bulb Readings	
	10·0	11·0
^{0}C	^{0}C	^{0}C
14	·23	·21
15	·26	·24

Against 14, for 1^{0} diff., change in press. $=\cdot 02$ in.

,, ,, ,, $0{\cdot}5^{0}$,, ,, $=\cdot 01$,,

,, under $10{\cdot}5^{0}$ diff. $=\cdot 23-\cdot 01$ in.

$=\cdot 22$ in. (1)

,, 15, for 1^{0} diff., change in press. $=\cdot 02$ in.

,, ,, ,, 0.5^{0} ,, ,, $=\cdot 01$ in.

,, ,, ,, under $10{\cdot}5^{0}$ diff. press. $=\cdot 26-\cdot 01$ in.

$=\cdot 25$,, (2)

From (1) and (2) we get,

Diff. in press. for 1^{0}, wet bulb $=\cdot 25-\cdot 22$

$=\cdot 03$.

,, ,, ,, $0{\cdot}5^{0}$, ,, $(14{\cdot}5-14{\cdot}0)=\frac{0{\cdot}5}{1{\cdot}0}\times\cdot 03$

$=\cdot 02$ approx.

$\therefore$ Pressure, against 14·5°, wet bulb under diff.

$$10 \cdot 5 = \cdot 23 + \cdot 02 = \cdot 25$$

$\therefore$ Actual Vap. Press.
Wet bulb under 0, $= \cdot 25$ in. of mercury.
Against 25·0°C, wet bulb,
under 0, max. vap. press. $= \cdot 93$ (mercury)

$$\therefore \text{ Relative Humidity} = \frac{\text{Actual pressure}}{\text{Max. pressure}}$$

$$= \frac{\cdot 25}{\cdot 93} \times 100$$

$$= 26 \cdot 9\% \text{ (about)}.$$

Dew Point.

Actual pressure	$= \cdot 25$
Against 4·0°, max. press.	$= \cdot 24$
,, 6·0°, ,, ,,	$= \cdot 28$
Diff. for 2·0°	$= \cdot 04$
$\cdot 25 - \cdot 24 = \cdot 01$	$=$ diff. in press.

For diff. of p. ·04 diff. in temp. $= 2 \cdot 0$°C.

,, ,, ·01 ,, $= \frac{\cdot 01}{\cdot 04} \times 2 \cdot 0 = 0 \cdot 5$°C

$\therefore$ Dew point $= 4 \cdot 0^{\circ} + 0 \cdot 5^{\circ}$

$$= 4 \cdot 5^{\circ}\text{C}.$$

Practical value of Humidity determinations.—Records of humidity and dew-point are kept at all meteorological stations. They are very helpful in giving information about rain and other weather conditions which is of special importance in modern aviation. This is also useful in keeping the plants healthy in a green-house, and for controlling the hygienic conditions in hospitals, public and private buildings.

DRY AND WET BULB HYGROMETER TABLE

The pressures of aqueous vapour are given in *inches* of mercury and the temperatures in *Centigrade*.

Readings of Wet Bulb	Difference between Dry and Wet Bulb Readings														
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0°C	·18														
2	·21														
4	·24														
6	·28														
8	·32														
10	·36	·33	·31	·29	·27	·24	·21	·19	·17	·14	·12	·10	·07		
11	·38	·36	·34	·32	·29	·27	·24	·22	·20	·17	·15	·13	·11	·09	·07
12	·41	·38	·36	·34	·32	·29	·27	·24	·22	·20	·17	·15	·13	·11	·09
13	·44	·41	·39	·36	·34	·32	·29	·27	·25	·23	·20	·18	·16	·14	·12
14	·47	·44	·42	·39	·37	·35	·32	·30	·28	·26	·23	·21	·19	·17	·15
15	·50	·47	·45	·43	·41	·38	·35	·33	·31	·29	·26	·24	·22	·20	·18
16	·53	·51	·48	·46	·44	·41	·39	·36	·34	·32	·29	·27	·25	·23	·21

17°C	·57	·54	·52	·49	·47	·45	·42	·40	·37	·35	·33	·31	·29	·27	·25
18	·60	·58	·55	·53	·51	·48	·45	·44	·41	·39	·36	·34	·32	·30	·28
19	·64	·62	·59	·57	·55	·52	·50	·48	·45	·43	·40	·38	·36	·34	·32
20	·68	·66	·64	·61	·59	·56	·54	·52	·49	·47	·44	·42	·40	·38	·36
21	·73	·70	·68	·65	·63	·61	·58	·56	·53	·51	·49	·47	·45	·43	·41
22	·77	·75	·73	·70	68	·65	·63	·60	·58	·56	·53	·51	·49	·47	·45
23	·82	·79	·77	·75	·73	·70	·67	·65	·63	·60	·58	·56	·54	·52	·50
24	·87	·85	·83	·80	·78	·75	·72	·70	·68	·66	63	·61	·59	·57	·55
25	·93	·91	·88	·85	·82	·80	·78	·76	·73	·71	·68	·66	·64	·62	·60
26	·98	·96	·94	·91	·88	·86	·84	·81	·79	·77	·74	·72	·70	·68	·66
27	1·04	1·02	·99	·97	·95	·92	·90	·87	·85	·83	·80	·77	·75	·73	
28	1·11	1·08	1·06	1·03	1·01	·98	·96	·93	·91	·89	·86	·83	·81		
29	1·17	1·14	1·12	1·10	1·08	1·04	1·02	1·00	·97	·95	·93	·90	·88		
30	1·24	1·21	1·19	1·17	1·15	1·12	1·09	1·07	1·04	1·02	1·00	·97	·95		
32	1·39	1·36	1·34	1·32	1·30	1·28	1·26	1·24	1·22						
34	1·56	1·53	1·51	1·49	1·47	1·45	1·43								
36	1·75	1·73	1·71	1·69	1·67										
38	1·95														
40	2·17														
42	2·41														

*When the difference between dry and wet bulb exceeds 14°C and when readings include fraction of a degree, pressure readings may be obtained by taking proportionate values, (as explained under "How to consult tables for proportional parts")

Prepared from the tables published by the Indian Meteorological Department.

CHAPTER XV

CALORIMETRY

Calorimetry.—The science of the measurement of quantities of heat is called "**Calorimetry**" and the apparatus with which we measure them are known as "**Calorimeters.**"

Temperature and Quantity of Heat.—The gain or loss of heat by a body is generally perceptible by the fall or rise of its temperature, which can be ascertained by a thermometer. This is not apparent at the time when a body is changing its state. The heat lost or gained by a body, during this change does not affect its temperature, which remains constant, and is called "Latent (or hidden) Heat."* When two bodies at different temperatures are placed in contact with each other, the hotter will give its heat to the colder one, and this transference of heat will continue until the temperature of both becomes the same. The temperature is, therefore, sometimes defined to be that physical condition of a body which determines which of the two bodies when placed in contact will part with its heat to the other. The body which loses heat is said to be at a higher temperature while that which gains heat at a lower temperature.

The quantity of heat present in a body does not, however, depend upon its temperature alone. A red hot needle may be much hotter than a bucketful of luke-warm water, but the latter will contain more heat than that present in the needle. A large quantity of water will require a greater amount of heat to get to boiling than a smaller one. The quantity of heat present in a body is proportional to its mass.

The loss or gain of heat by a body depends also upon the material of which the body is made. Equal masses of different bodies, when cooled or heated through the same range of temperature, will give out or gain different

---

*We shall explain the Latent Heat of a body later on.

quantities of heat. Or, if equal amounts of heat be imparted to equal masses of various bodies, their temperatures will rise by different amounts.

More generally, if Q=quantity of heat gained or lost by a body of mass$=m$, and its rise or fall of temperature $=t^0$, $Q=m\times s\times t$ ......(1)

where s is a constant depending upon the nature of the body.

Unit of heat :—In equation (1) if s be taken to be unity, as in the case of water, Q will be=1, when $m=1$ and $t=1$. Hence we define our '**Unit of Heat**' to be that quantity of heat which is gained or lost by a unit mass of water during a rise or fall of one degree of temperature. In the C. G. S. system of units, unit of mass is one gram, and unit degree is 1^0 Centigrade. Thus the 'Unit of Heat' in the C. G. S. system of units is that quantity of heat which when given to or taken from one gram of water, raises or lowers its temperature by one degree Centigrade. This is called a **Calorie** or **Therm**, while a British Thermal Unit (B. T. U.) is the quantity of heat lost or gained by one pound of water in cooling or heating through 1^0 Fahrenheit. The C. G. S. unit or calorie is generally used in all scientific work.

Capacity for heat or Thermal Capacity.—It is the quantity of heat lost or gained by a body when it cools through or gets heated by unit degree of temperature. Or from equation (1) if $t=1^0$, the capacity for heat of a body will be $Q=m\times s$ ...(2)

since the factor s is taken to be unity in case of water, Thermal capacity of water is

$$Q=m=\text{mass of water (numerically.)}$$

A body, whose thermal capacity is Q units of heat, is thermally equivalent to $Q=m$ grams of water. The mass of water thermally equivalent to a body is, therefore called the '**Water Equivalent**' of the body. It is the mass of water which will absorb or give out the same quantity of heat, as taken in or given out by a mass m of a body in changing its temperature by 1^0C. It is usually indicated $W=m\times s$, where m=mass and s=sp. heat of the body.

Specific Heat.—The ratio of the capacity for heat of a body and the capacity for heat of an equal mass of water is its "**Specific Heat**". Or it may be defined as the ratio of the quantities of heat lost or gained by a body and by an equal mass of water, the range of temperature through which the cooling or heating takes place being the same in each case.

If
- Q = quantity of heat lost or gained by a body
- Q' = quantity of heat lost or gained by an equal mass of water.
- s = specific heat of the body.
- t^0 = change in temperature both of the body and water.
- m = mass of the body or water.

$Q = m \times s \times t$

$Q' = m \times 1 \times t$

since specific heat of water is taken to be $= 1$

Specific heat of the body

$$\frac{Q}{Q'} = \frac{m \times s \times t}{m \times 1 \times t} = s.$$

Specific Heat for water, $s=1$, follows from the definition of the "Calorie," given above. In the equation

$Q = m \times s \times t$

$s = 1$ if $\begin{cases} Q = 1 \text{ unit of heat.} \\ m = 1 \text{ gm.} \\ t = 1^0\text{C.} \end{cases}$

Since the specific heat is a ratio, it is only a number and when specifying it no unit is used with it.

Principle of Transference of Heat.—Whenever there is an exchange of heat between different parts of a system of bodies from the Law of "Conservation of Energy," (the total amount of heat present in the system does not vary, if there is no loss or gain of heat to or from the surrounding bodies) it follows that, Heat lost by hot bodies=Heat gained by cold bodies.

This is called the, "Principle of transference of heat" and forms the basis of the "method of mixtures" for determining the "Specific Heat" and the "Latent Heat" of bodies, as described below.

Experiment 50.—**To determine the Specific Heat of a body by the method of mixtures.**

Why the θ ...

Apparatus.—Copper hypsometer with tube to take the solid, calorimeter with stirrer, lid and a piece of felt or flannel, two thermometers * (preferably $\frac{1}{2}^0$), balance with weights, a retort stand with clamps, a beaker and a tripod stand.

Method.—The solid in fragments is put into the copper tube of the hypsometer and the cork through which a thermometer (full degree) passes is fitted to it by tilting the tube so as to keep the bulb safe from breaking. The tube is then fitted to the hypsometer, previously filled with water, and adjusted to the stand as shown in Fig. 67 The water is then heated to boiling. The water in the calorimeter, with stirrer (and not the lid) is first weighed empty and then $\frac{2}{3}$ filled with water. The temperature of the solid in the hypsometer rises quickly at first and slowly afterwards until it reaches a maximum (about 95°C at the ordinary atmospheric pressure). This temperature, which should remain constant for at least about 5 mts., is read and recorded. The temperature of the water in the calorimeter, which is wrapped round by the piece of flannel and covered with lid immediately after weighing, is now taken by the other thermometer (half degree). First make the cork in the tube loose, and then the one surrounding it, and transfer the solid to the calorimeter, without any unnecessary delay. The water in the calorimeter is thoroughly stirred and the highest *steady* temperature is read and recorded. The lid and the thermometer being removed, the calorimeter is weighed again. The difference of this and the second weighing gives the weight of the solid taken.

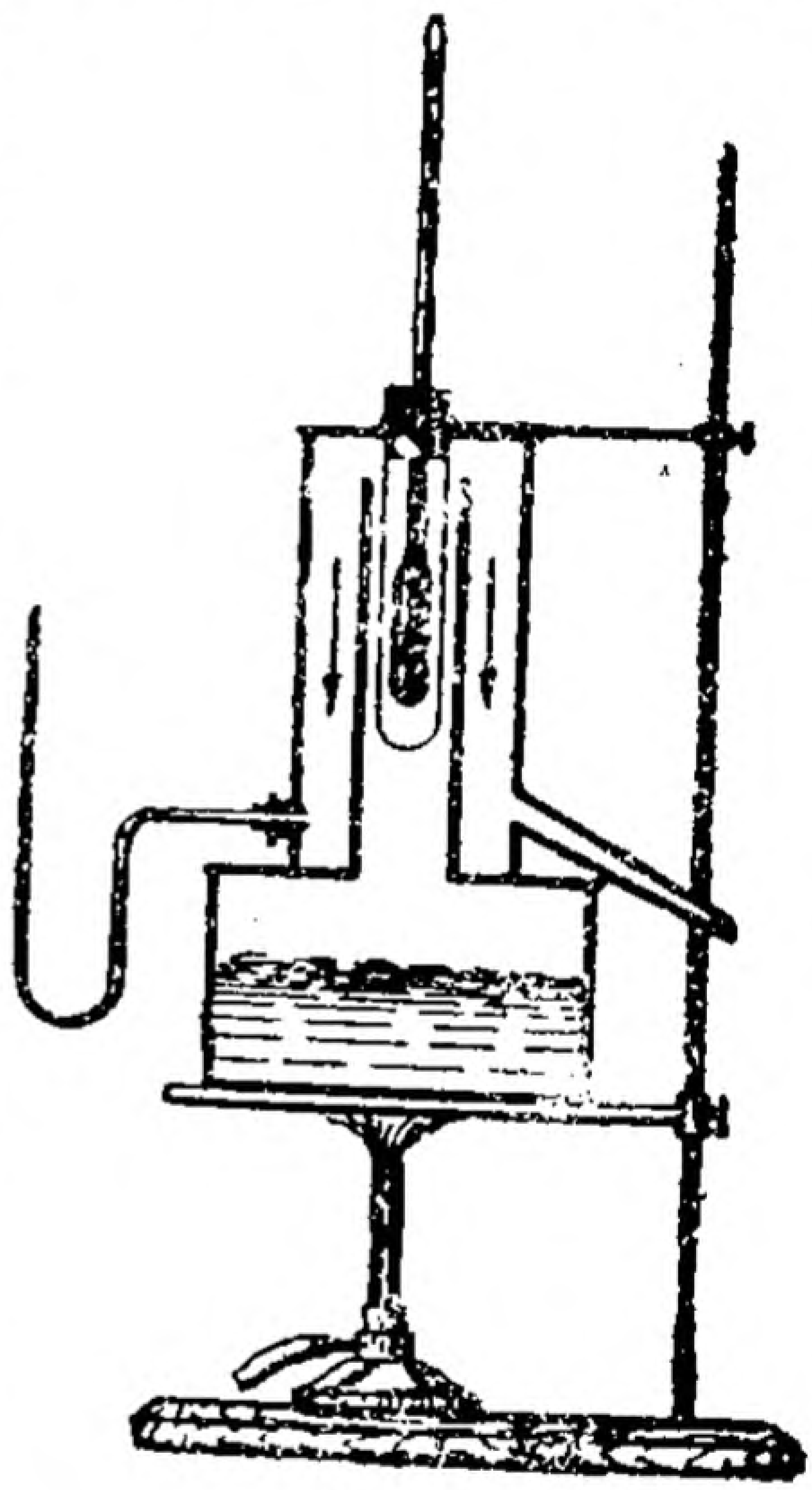


Fig. 67

*If two $\frac{1}{2}^0$ thermometers are not available, at least one of them should be $\frac{1}{2}^0$.

Observations :

1. Weight of empty calorimeter with stirrer $= m_1$ gms.
2. Weight of empty calorimtter + water $= m_2$,,
   $\therefore$ Weight of water only $= (m_2 - m_1)$,,
3. Weight of calorimeter + water + solid $= m_3$
   $\therefore$ Weight of solid only $= (m_3 - m_2)$
4. Initial temperature of hot solid $= t_1{}^\circ$C.
5. Initial temperature of water $= t_2{}^\circ$C.
6. Final temperature of the mixture $= \mathrm{T}^\circ$C.
   $\therefore$ Fall of temperature $= (t_1 - \mathrm{T})^\circ$C
   and rise of temperature $= (\mathrm{T} - t_2)^\circ$C

Specific Heat of copper (of which the calorimeter is made) $= \cdot095 = \cdot1$ nearly.

Calculations and Results :

*Water equivalent of calorimeter = mass $\times$ sp. heat
$= m_1 \times \cdot 1 = \mathrm{W}$ gms.

Let specific heat of solid $= s$ (say)

Heat lost by the hot solid = Heat gained by water + Heat gained by Calorimeter.

Mass $\times$ sp. heat $\times$

fall of temperature = mass $\times$ sp. heat $\times$ rise of temp.
+ mass $\times$ sp. heat $\times$ rise of temp.

$$(m_3 - m_2) \times s \times (t_1 - \mathrm{T}) = (m_2 - m_1) \times 1 \times (\mathrm{T} - t_2)$$
$$+ (m_1 \times \cdot 1) \times (\mathrm{T} - t_2)$$
$$= [(m_2 - m_1) + \mathrm{W}] \times (\mathrm{T} - t_2)$$

$$\therefore\ s = \frac{(m_2 - m_1) + \mathrm{W}}{m_3 - m_2} \times \frac{\mathrm{T} - t_2}{t_1 - \mathrm{T}}$$

$$= \frac{\text{mass of water} + \text{water equivalent of cal.}}{\text{mass of solid}} \times \frac{\text{rise of temp.}}{\text{fall of temp.}}$$

*Water equivalent of calorimeter may be determined previously by a preliminary experiment described hereafter.

Precautions :—1. Water equivalent of calorimeter, either determined by a separate experiment or calculated as above, and allowed for.

2. To minimise error due to radiation of heat, calorimeter is wrapped round by flannel (non-conductor of heat) and rise of temperature not to exceed 15°C.

*3. Rise of temperature about 10°C temperature read to 0·1°C on a half degree thermometer in the calorimeter.

4. Transfer of solid to the calorimeter to be quick. Its temperature to be kept constant for more than 5 mts.

5. Solid to be taken in fragments or small chips so as to attain high temperature, and to give up its heat quickly.

6. Water in the calorimeter to be well stirred, and calorimeter kept covered as far as possible to avoid evaporation.

7. Calorimeter to be weighed when cold and weighing not to be taken beyond centigrams (0·01 gms.)

8. To avoid error in this weight of solid due to evaporation of liquid, the calorimeter with the liquid is weighted with the *lid* before and after dropping the solid.

9. A wooden partition is placed between the hypsometer and the calorimeter.

Sources of Error.—As we measure quantities of heat indirectly by the rise or fall of temperature, for the success of the experiment it is extremely important to measure temperature accurately. But this is futile if the readings on the two thermometers happen to differ by as much as 1·0°C, or if the loss of heat due to radiation be too large. Similarly under the circumstances in which the experiment is generarly performed, it is not only unnecessary but sometimes aggravates the error in the final result if weighings are carried to the third place of decimals. To eliminate, allow for, or reduce to the minimum some of these sources of error, the student should carefully study the following :

(1) If temperature of the calorimeter be read on a thermometer graduated in degrees, the rise of temperature should not be less than 10°C, and may be even a little more. For even if the temperature be read correctly up to 0·1°, the error will be $\frac{1}{10}$ of a degree, $\frac{1}{100}$ of 10°, *i.e.*, 1%. If it be

*This may be ascertained by another preliminary experiment as explained later.

correct to 0·2°C as is generally the case, for we can at best estimate correctly by eyesight $\frac{1}{5}$ of a degree, the error will amount to 2%. With a thermometer graduated to half degrees we can correctly read the temperature upto 0·1°C, and if the rise of temperature be taken between 10·0° and 5·0°C, the error will be between 1% and 2%. For half degree thermometer the rise should never be less than 5·0°C and may even slightly exceed this limit.

(2) When full degree thermometers are used, it is sheer waste of time to weigh correct to the last milligram. For with an error of 0·2°C in reading the thermometer, the weight correct to a milligram will in no way improve the results. Loss in weight due to evaporation, and the drops of water which remain sticking to the thermometer on its removal, are more than sufficient to contract the attempt to bring out correct results, by taking weights to such a limit. For full degree thermometers, it is quite unnecessary to go beyond 0·1 gm. weights, and if half-degree thermometers are available, these may be carried to 0·01 gm.

(3) If the rise of temperature exceeds 15°C, the loss of heat due to radiation will be too great, and in spite of all the precautions taken the result may be unsatisfactory. If the double-walled calorimeter be not available, as is usually the case, to minimise the error due to this source, the calorimeter should have a polished outside surface, should be carefully wrapped with a non-conducting material like felt or flannel, which should be thoroughly clean and dry, should be placed on a pad of the same non-conducting material, and should be covered by the lid as far as possible. The solid taken should be in small fragments, so that it gives up its heat quickly to the water in the calorimeter, and the thermometer attains its highest steady temperature in a short time and consequently very little time is allowed for the radiation of heat.

It is always advisable to perform a preliminary experiment, by taking weights of the solid and the water in the calorimeter correct to gms , and temperatures correct to degrees, to get the desirable rise of temperature. This will not only allow for the errors given above, but would initiate the student to the drawbacks of his apparatus and his own shortcomings in the performance of the experiment. The solid may be heated for 5 or 10 mts. in boiling water in the

beaker, its initial temperature being noted and the final temperature recorded after thorough stirring. This would give him an idea of the approximate weights to be taken of the solid and the water in the calorimeter.

(4) Although the heat absorbed by the calorimeter is allowed for in the calculations, it would add to the accuracy of the result if the calorimeter used is made of thin sheet of copper to make it as light as possible. It will then absorb a smaller amount of heat and the amount of water used will be comparatively larger. The vessel should not be too wide, otherwise evaporation of water will be greater.

(5) Before its transfer to the calorimeter, the temperature of the solid should be kept steady for at least 5 mts. to ensure that the whole of the solid has attained to the temperature of the bath. This should be about 98·0°C at the ordinary atmospheric pressure. Its being appreciably lower than this is a sure sign of the bulb of the thermometer either being not in contact with the solid on all sides, or the solid not being completely surrounded by the hot steam, or the thermometer being faulty.

(6) The water in the calorimeter should be thoroughly stirred, so that the thermometer correctly registers its final temperature. The latter should neither touch the bottom nor the sides of the calorimeter. Thermometer should never be used in place of the stirrer. Stirring should not be overdone so as to splash the water or to make the cover wet, specially when it is made of cardboard.

(7) In the standard thermal equation used for the calculation of the results it is assumed that there are no losses of heat to the outside bodies. The whole of the heat lost by the hot solid is taken by the water in the calorimeter and the material of which it is made. But some heat is unavoidably lost by the solid during its transfer to the calorimeter.

Several devices are used or suggested to make this loss as small as possible. If, however, the ordinary heater, commonly in use, be employed, and proper care be taken to make the transfer as quick as possible, the heat lost during the transit is so small as to be conveniently negligible as compared with other sources of error.*

*Note.—We may confess that no amount of description of precautions to be taken or sources of error to be avoided or allowed for, will help the student in getting good results. His own practice in performing the experiment along right lines will help him a great deal in this respect.

NOTE.—To determine the specific heat of a liquid by the method of mixtures, proceed exactly in the same manner as described above. The water in the calorimeter is replaced by the liquid and the specific heat of the solid used is known previously. For inflammable solids, the solid instead of being heated by steam is cooled to 0°C by surrounding it, with pounded ice. On dropping the solid into the liquid, it gains heat from the comparatively hot liquid. The calorimeter being at a temperature below that of the air surrounding it gains heat instead of losing it by radiation as in the previous case and requires wrapping with a non-conducting material.

Exercise.—To determine the temperature of the Bunsen burner by the method of mixtures.

[**Hint.**—A copper or brass ball is heated in a Bunsen flame for sufficiently long time so that it takes the temperature of the flame. This will be apparent by its red hot colour. It is then dropped into the calorimeter, avoiding any splash of water and the final temperature recorded. The specific heat of the solid (copper or brass) being known, its initial temperature, which in this case will be the temperature of the flame, is calculated as in the case of the specific heat.

Experiment 51.—**To determine the water equivalent of a copper calorimeter.**

Apparatus:—A thin copper calorimeter with stirrer and lid, two half-degree thermometers, beaker with tripod and wire gauze, retort stand with thermometer clamp, and a Bunsen burner.

Method :—Some water is heated in the beaker and in the meanwhile calorimeter with stirrer is first weighed empty and then ¾ full of water. Calorimeter is well wrapped with felt or flannel, is covered with the lid and the initial temperature of water is carefully recorded correct to 0·1°C. The temperature of hot water being read, sufficient of it is quickly added to the calorimeter so that the rise of temperature is about 10·0°C or thereabouts. The water is thoroughly stirred and the final temperature observed as before correct to the first place of decimal. On cooling, the calorimeter is weighed once again.

Observations :

(1) Weight of calorimeter with stirrer $= m_1$ gms.
(2) ,, ,, + cold water $= m_2$ gms.
$\therefore$,, ,, cold water only $= (m_2 - m_1)$ gms.
(3) Temperature of hot water $= t_1$°C
(4) Initial ,, ,, cold water $= t_2$°C
(5) Final temperature of mixture $=$ T°C
(6) Weight of calorimeter + cold water + hot water $= m_3$ gms.
$\therefore$,, ,, hot water added $= (m_3 - m_2)$ gms.
Rise of temperature $= (T - t_2)$°C
Fall ,, $= (t_1 - T)$°C

Calculations and results :

Let the required water equivalent be $= w$

$\left.\begin{array}{l}\text{Heat gained by cold water} + \\ \text{Heat gained by calorimeter}\end{array}\right\} =$ heat lost by hot water.

mass $\times$ sp. heat $\times$ rise of temp.
+ water-equivalent $\times$ rise of temp.
= mass $\times$ sp. heat $\times$ fall of temp.

$$(m_2 - m_1) \times 1 \times (T - t_2) + w \times (T - t_2)$$
$$= (m_3 - m_2) \times 1 \times (t_1 - T)$$
$$\therefore\ w = \frac{(m_3 - m_2)\ (t_1 - T)}{T - t_2} - (m_2 - m_1)$$
$$= \frac{\text{mass of hot water} \times \text{fall of temp.}}{\text{rise of temp.}}$$
$$- \text{mass of cold water.}$$

Precautions :—Same as in the previous experiment.

CHAPTER XVI

CALORIMETRY—(Contd.)

Latent Heat.—As explained in Chapter XIII the change of state of a body from solid to liquid (liquefaction) or from liquid to vapour (vaporisation), or the reverse process from liquid to solid (solidification), or from vapour to liquid (condensation), takes place always at definite temperatures, under normal conditions of pressure, and these temperatures remain constant so long as the change is taking place. This change of state is always accompanied by the absorption or evolution of heat. Every gram of a substance, during its change of state, takes in or gives out a definite amount of heat, called its **Latent Heat.**

Latent Heat of Water or Fusion of Ice.—It is the amount of heat required to melt 1 gm. of ice at 0°C to water at the same temperature. The same amount of heat will be evolved in the reverse process when 1 gm. of water at 0°C solidifies into ice, without any change in the temperature.

We can measure the 'Latent Heat' of water by the method of mixtures as in the case of specific heat of bodies, by the fall of temperature of water which gives up its heat to melt the ice. In order to get good results, we have, therefore, to take all the necessary precautions taken in the measurement of temperatures and the determination of specific heat For success in these experiments of change of state, we have, however, to be more careful in taking these precautions. We shall discuss some of the more important of these as follows :—

(1) To reduce the percentage error in reading temperatures correctly, even if we use half degree thermometers, it is necessary to have an appreciable fall of temperature, usually of about 10° or even 15°C. The temperature is carefully read to 0·1°C with a half degree thermometer.

(2) All the time that the temperature is falling below that of the room, specially when the fall is great, the calorimeter takes up heat from the surrounding air. This source of error is too great to be allowed for entirely or minimised by wrapping the calorimeter with felt or flannel. In wet weather, moreover, due to this cooling there is a deposit of dew on the surface of the calorimeter and the water-vapour in condensation gives up a large amount of its latent heat to the vessel. To allow for this a preliminary experiment is necessary to estimate the amount of ice to be used in bringing about a desired fall of temprature in the water taken in the calorimeter. The latter is filled $\frac{2}{3}$ with water and without weighing the water, its initial temperature is noted and one or two large pieces of ice are added to it after drying the ice with blotting or filter paper. The water is thoroughly stirred keeping the ice under water all the while by pressing it with the stirrer. When the whole of the ice is melted the lowest temperature on the thermometer is noted.

(3) To avoid the melting of ice before its introduction to the calorimeter, it is not to be broken into too many small pieces, and a larger lump of ice takes time to absorb the necessary amount of heat from the surrounding water before melting. The amount of heat absorbed by the calorimeter from surrounding air, is, therefore, still great.

(4) To allow for this gain of heat, the initial temperature of water in the calorimeter is taken to be as much above the room temperature as the estimated final temperature is to be below it when the whole of ice gets melted. If the fall of temperature is to be 10°C and the temperature of the room is 25°C, water in the calorimeter should be taken at 30°C. The fall of temperature being 10°C, the final temperature would be $(30-10)° = 20°C$, which is 5° below the room temperature. During the first half of the cooling of calorimeter from 30°C to 25°C its temperature will be above the room temperature and it will lose heat by radiation ; while during the second half when the temperature falls from 25°C to 20°C, it is colder than its surroundings and hence it will absorb heat. As the radiation and absorption of heat to or from the surroundings is proportional to the difference of its temperature and that of the

air, it is reasonable to assume that it loses as much heat during its fall to room temperature as it gains during its fall below it or that it neither loses nor gains heat to or from its surroundings.

(5) The weight of the ice melted is determined by the increase in the weight of water taken. Weighings are to be taken very carefully correct to ·01 gm. as every gram of ice takes an appreciably large amount of heat (80 calories) in melting to water at 0°C, and slight error in the weight of ice will entail a large error in the determination of its latent heat If warm water be taken, during the summer, due to rapid evaporation the weight of water in the calorimeter is not correctly determined and hence it is much better not to warm the water when the room temperature is high, and the calorimeter is kept well covered during weighings. The weight of the cover may be determined separately before hand. When the air of the room is moist during the rainy season, the temperature of the calorimeter should not fall beyond a few degrees and if necessary, before weighing, the dew depositedd on the outside surface of the calorimeter should be wiped off. The final weight of the calorimeter is generally taken when it attains the room temperature.

(6) To determine the correct weight of ice melting within the water it is also necessary that it should be dry before it is dropped into the calorimeter. The water at its surface is carefully soaked by the blotting or filter paper. Care should be taken that no water is removed from the calorimeter along with the bulb of the thermometer. To avoid this either the thermometer should be made wet before it is put into the water or the last drop sticking to it should be removed by touching it with the sides of the calorimeter.

Experiment 52. **To determine the Latent Heat of water (or of fusion of ice) by the method of mixtures.**

**Note.*—As before no hard and fast rules can be laid down to ensure good results. A careful experimenter will study for himself the weak points of the experiment and will be able to get results not very far from the actual ones. Considering all the sources of error the results obtained should always be below 80 calories and not above it.

Apparatus.—A calorimeter with cover, stirrer and a piece of flannel, a half degree thermometer, balance with weights, some pieces of ice in a dish, a beaker on a tripod stand with wire gauze and burner, a piece of blotting paper.

Method.—After performing the preliminary experiment, the calorimeter with stirrer is first weighed without the cover. The weight of the cover is then added to it, meanwhile some water is heated in the beaker. When its temperature is a few degrees above the initial one, estimated previously for the desirable fall, the necessary amount is poured into the calorimeter; and its weight determined with the cover on. The calorimeter being wrapped tightly with flannel, a lump or two of ice after being dried properly with blotting paper is quickly dropped into it. The stirrer and thermometer being placed in position, the water is thoroughly stirred, keeping the piece of ice well under water, until the whole of it melts. The lowest steady temperature reached is carefully noted correct to 0·1°C. If there were some moisture deposited on the surface of the calorimeter it is wiped off and the vessel allowed to attain the temperature of the room, keeping it well covered all the time. The thermometer is removed without taking any drop of water out with it and the calorimeter is finally weighed along with the stirrer and the cover, Observations are recorded as below.

Observations:

Room temperature $=\ldots{}^{\circ}C$
Final temp. in the preliminary experiment $=\ldots{}^{\circ}C$
Fall of temp. (app.) below the room temp. $=\ldots{}^{\circ}C$

1. Weight of calorimeter + stirrer $= m_1$ gms.
2. ,, ,, + stirrer and cover $= m_2$ gms.
3. ,, ,, + warm water $= m_3$ gms.

∴ ,, ,, + warm water taken $= (m_3 - m_2)$ gms.

4. Initial temperature of water $= t_1{}^{\circ}C$
5. Final temperature of mixture (after melting of ice) $= T^{\circ}C$

∴ Fall of temp. $= (t_1 - T)^{\circ}C$.

6. Weight of cal. etc. + water + ice $= m_4$ gms.

∴ ,, ,, ice only $= (m_4 - m_3)$ gms.

Calculations and result :

Let the latent heat of water be $= L$ calories
and water equivalent of calorimeter $= W$ gms.

$$\left.\begin{array}{l}\text{Heat gained by ice in melting} + \\ \text{Heat gained by melted ice}\end{array}\right\} = \begin{array}{l}\text{Heat lost by} \\ \text{warm water} + \\ \text{Heat lost by} \\ \text{calorimeter.}\end{array}$$

$$\text{Wt. of ice} \times L + \text{Wt. of ice} \times \text{final temp.} = \text{Wt. of water} \times \text{fall of temp.} + W \times \text{fall of temp.}$$

$$(m_4 - m_3) \times L + (m_4 - m_3) \times T = (m_3 - m_2 + W) \times (t_1 - T)$$

$$\therefore \quad L = \frac{(m_3 - m_2 + W) \times (t_1 - T)}{m_4 - m_3} - T$$

$$= \frac{(\text{wt. of warm water} + \text{water equivalent})\ \text{fall of temp.}}{\text{wt. of ice melted}}$$

—final temperature.*

Precautions : 1. Fall of temperature to be between 10° and 15°C.

2. To avoid error due to radiation of heat, warm water is taken as much above room temperature as the final temperature is below it.

3. Temperature read correct to 0·1°C.

4. Weights taken correct to 0·1 gm.

5. Ice properly dried, kept under water and thoroughly stirred.

6. Calorimeter kept covered as far as possible.

Latent Heat of Steam (or of Vaporisation of water).—It is the amount of heat in calories, necessary to convert one gram of water at its boiling point to one gram of steam at the same temperature. The same amount of heat will be given up by one gram of steam in condensing into water, without any change in its temperature. Unlike the latent heat of water in which heat is absorbed by ice in melting, the quantity of heat given out by steam in condensing into

* Note—Since some ice melts outside the water in the calorimeter, and heat is taken by the cold calorimeter from the surroundings. fall of temperature in this equation is less and weight of ice melted is more than what actually should be the case. The former being the numerator and the latter the denominator of the expression the right-hand side of this equation, the result has, therefore, the tendency of being smaller.

water is ascertained by the method of mixtures for the determination of its Latent Heat.

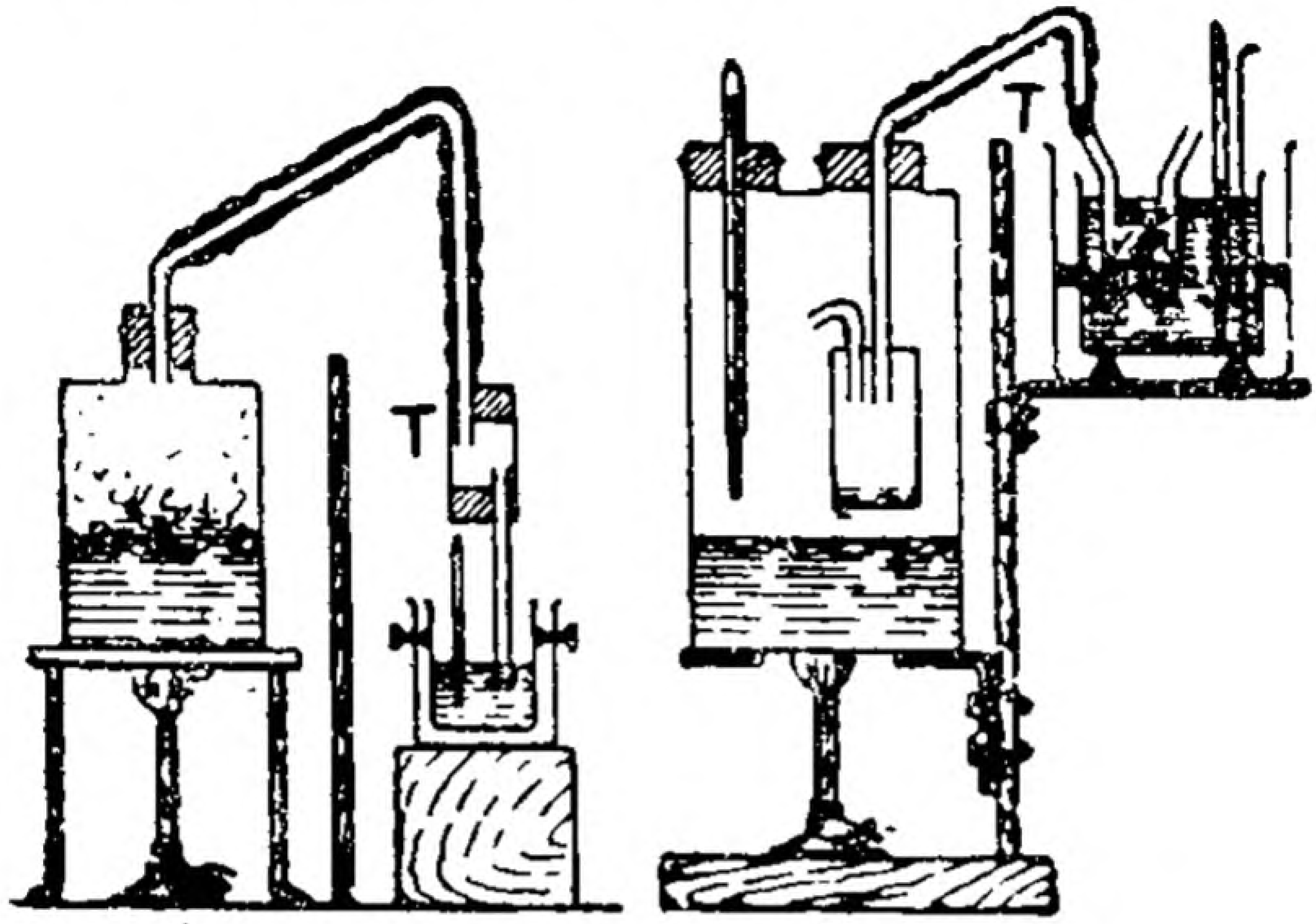


Fig. 68.

As a comparatively large amount of heat is lost by a gram of steam (536 calories) before it condenses into water, a small quantity of it will raise the temperature of the calorimeter to a very great extent. Special care is to be exercised and proper precautions taken to determine the exact weight of the condensed steam and to allow for the radiation correction.

Several apparatus with special devices, with "steam-trap" and "separate condensers" have been (see Fig. 68) devised, to determine the proper weight of dry steam which on condensation gives up the whole of its latent heat to the water in the calorimeter. But the apparatus is so elaborate that it does not admit of easy manipulation by the beginners. The balances, thermometers and the calorimeters with which the student has to work are, moreover, not of a standard to justify the use of such complicated apparatus.

It is no doubt that, due to various causes, some beyond the control of the young experimenter, the results obtained are not of a very high accuracy. But at this initial stage the aim of the practical work is not to get very

accurate results, but to initiate the scholar to ordinary manipulations, and to create in him the habit of taking correct observations, understanding and appreciating the value of sources of error in an experiment, which may lead to accurate results.

To attain this object we describe below a very simple form of apparatus [Fig. 68. (*a*)] which had lately been in use in practically all laboratories for junior work, and the results obtained with this are quite compatible with its simplicity and ease of manipulation. But before we do so, we would like to point out some main features of the apparatus used and the sources of error peculiar to the experiment.

(1) The principal source of error is the determination of the correct weight of the steam condensed in the calorimeter. As this is obtained by weighing the calorimeter after the steam has passed through it, it is necessary that the drops of water into which steam is condensed during its passage through the delivery tube, or small drops of water in the form of spray, do not get into the calorimeter. For this purpose the delivery tube used is wide, it is not very long, is bent towards the heater, and is carefully covered with non-conducting cotton wool. Water drops collecting at the mouth of the tube should be removed by a piece of blotting paper, before introducing the tube into the calorimeter.

(2) The steam condensed should not be less than 4 or 5 gms. or the percentage error in determining its weight will be too large. This would raise the final temperature to a great-extent if the water in the calorimeter is too small and hence a greater loss of heat due to radiation. To estimate the amount of steam to be condensed, and the quantity of water to be taken in the calorimeter to keep the rise of temperature within proper limits, a preliminary experiment is performed. The calorimeter is filled $\frac{2}{3}$ with water, and without finding the weight of water, its temperature is noted and steam is passed through it for some time so that the rise of temperature does not exceed 20°C. This would give a rough idea how long the steam is to be passed into the amount of water taken in the calorimeter, to get the permissible rise of temperature.

(3) As the final temperature is pretty high, loss of weight of water in the calorimeter occurs due to evaporation. To avoid this, the calorimeter is properly covered and is weighed along with the cover in the final weighing. Weights are taken with greater care and accuracy to milligrams.

(4) To diminish the error due to evaporation of water and the loss of heat due to radiation, water in the calorimeter is cooled by dropping a little ice into it, so that its temperature is 10°C below that of the room. If the estimated rise be 20°C, its final temperature will be 10°C above the room temperature. The gain of heat from the surroundings during the time that the temperature rises to that of the room, will be compensated by its loss, during the interval when the temperature is above that of the air. As the final temperature exceeds only by 10°C and not 20°C as in the previous case, when no ice is added to the water, the evaporation will consequently be less and hence the error in the weight of steam condensed will be smaller.

(5) Water at ordinary atmospheric pressure obtained in the laboratory does not boil at 100°C, but at a temperature a few degrees below it. The initial temperature of steam may either be taken by a thermometer inserted in the boiler (this is not shown in the figure), or the Barometer may be read correct to millimetres and the boiling point calculated. The thermometer used in the calorimeter should be graduated to half degrees so as to read correctly to 0·1°C.

(6) The delivery tube should be immersed under water so that no steam escapes from its surface and condenses on other parts of the calorimeter. The water should be kept thoroughly stirred while the steam is passing, so that the thermometer correctly registers the final temperature.

(7) Care should be taken not to remove any drops of water along with the thermometer, when it is removed from the calorimeter. The last drop should either be wiped off by touching the side of the calorimeter or the thermometer should be moistened previously.

(8) The calorimeter should be thoroughly wrapped with flannel and should be placed on a pad of felt. In order to stop the heat radiated by the boiler from arriving at the

calorimeter, a wooden partition (board) should be placed between them.*

Experiment 53. **To determine the Latent Heat of steam, by the method of mixtures.**

Apparatus.—A steam heater, with wide bent glass delivery tube padded with cotton wool, a calorimeter with stirrer, a block of wood, a half degree thermometer, a burner with tripod stand and pieces of blotting paper.

Method and Manipulations.—The apparatus being fitted as shown in the figure the water in the boiler is heated, and the calorimeter with stirrer is first weighed empty without cover, and the weight of the cover (separately determined) is added to it. The calorimeter is filled $\frac{3}{4}$ with cold water and its temperature noted immediately before passing the steam through it. The barometer is read and the temperature of steam calculated from it. When steam is profusely coming out of the delivery tube the last drop of water at its mouth is removed by the blotting paper, and the tube is quickly introduced into the calorimeter, so that its end is well under water.

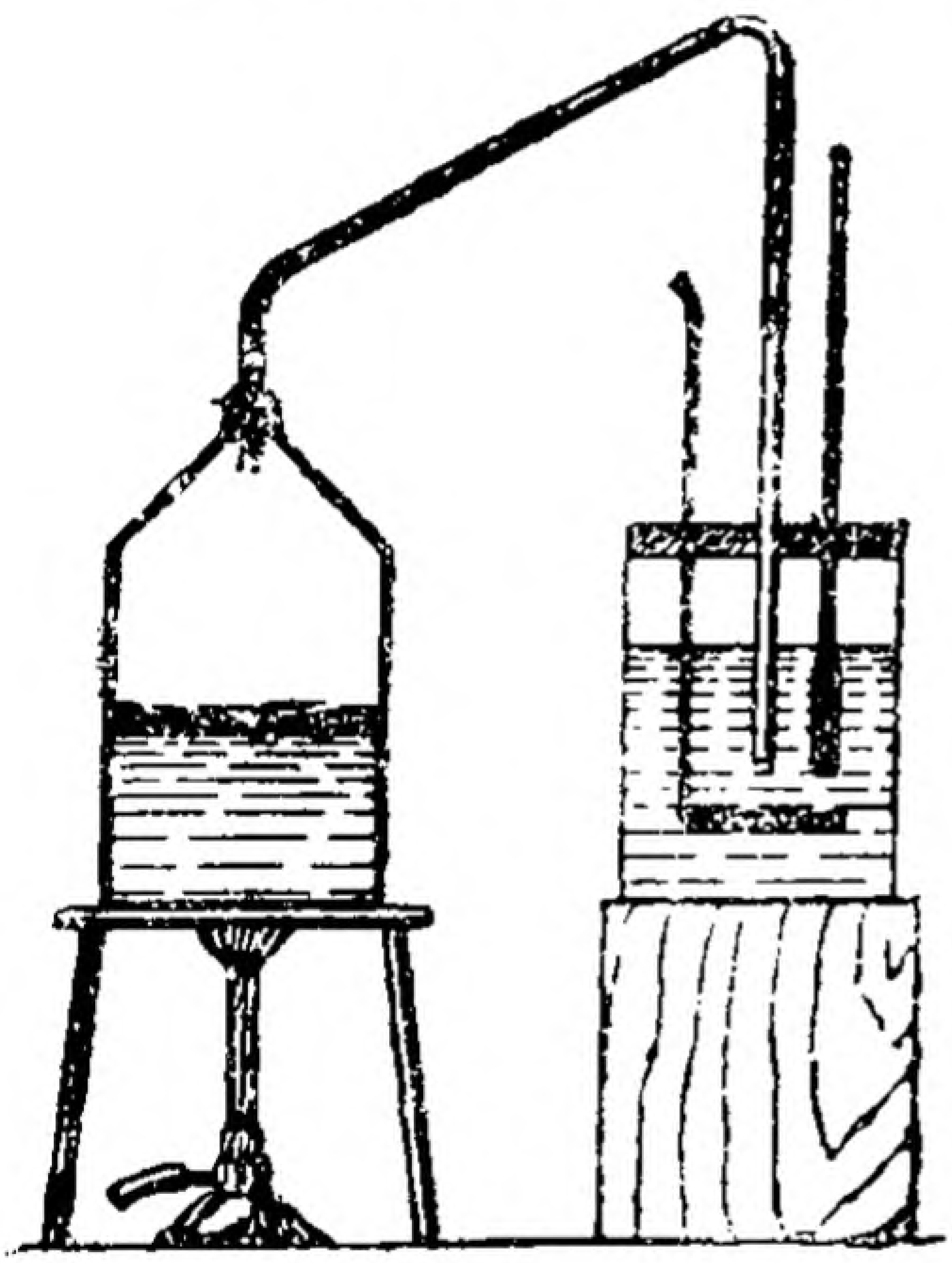


Fig. 69.

The calorimeter covered on all sides with flannel, is placed on the block of wood. The calorimeter being covered, water is thoroughly stirred and the highest steady temperature is recorded correct to 0·1°C. On removal of the delivery tube, the calorimeter with stirrer, and its contents is weighed with its cover on. Thermometer is removed without taking out any drop of water with it.

* *Note*—Practically all the sources of error lead to an error in the weight of steam condensed. The tendency of these is to lower the result, 520 calories or thereabouts is generally expected which is about 3 p. c. lower than the correct value.

Observations.

Room temperature $= \dots ^\circ C$

Final temperature (preliminary experiment) $= \dots ^\circ C.$

Approximate rise of temperature $= \dots ^\circ C.$

(1) Weight of empty calorimeter with stirrer $= m_1$ gms.

(2) ,, ,, ,, and cover $= m_2$,,

(3) ,, ,, ,, + cold water $= m_3$,,

∴ ,, ,, cold water only $= (m_3 - m_2)$,, $=$ M gms. say

(4) Temperature of steam (by calculation) $= t_1 ^\circ C$

(5) Initial temperature of cold water $= t_2 ^\circ C$

(6) Final temperature of water, after passing steam $= T^\circ C$

∴ Fall of temperature $= (t_1 - T)^\circ C$

and Rise ,, $= (T - t_2)^\circ C$

(7) Weight of cal. etc. after condensation of steam $= m_4$ gms.

∴ Weight of steam condensed $= (m_4 - m_3)$

Calculations and result.

Let the latent heat of steam be $=$ L calories

and water equivalent of calorimeter $=$ W grams.

$= m_1 \times \cdot 095$

$= m_1 \times \cdot 1$ (App.)

$$\left.\begin{array}{l}\text{Heat lost by Heat lost by}\\ \text{steam} \quad + \quad \text{condensed}\\ \text{in condensation steam}\end{array}\right\} = \begin{array}{l}\text{Heat gained}\\ \text{by cold water}\end{array} \begin{array}{l}\text{Heat gained}\\ +\text{by calori-}\\ \text{meter etc.}\end{array}$$

Wt. of steam × L + wt. of steam × fall of temp.
= wt. of cold water × rise of temp.
+ W × rise of temp.

$$m \times L + m(t_1 - T) = (M + W)(T - t_2)$$

$$\therefore L = \frac{(M+W)(T-t_2)}{m} - (t_1 - T).*$$

**Note.*—If all the steam is not condensed within the water in the calorimeter, m will be more and $(T - t_2)$ less than the actual value. Rise of temperature will be smaller and $(t_1 - T)$ will be greater and hence the value of L found will generally be less than the actual value. Radiation of heat also tends to lower the result.

Precautions :—

1. Steam condensed should be dry, *i.e.*, free from drops of water.

2. The weight of steam condensed to be about 4 or 5 grms.

3. To avoid evaporation, calorimeter weighed while covered, and initial temperature of water to be below the room temperature by half the rise of temperature.

4. Last drops of water removed from the delivery tube.

5. Weights to be taken correct to milligrams, and temperature to 0·1°C.

6. Water thoroughly stirred before taking the final temperature.

7. Water equivalent of calorimeter to be noted, and allowed for.

8. Drops of water sticking to thermometer not to be removed, but retained in the calorimeter.

Radiation.

Newton's law of cooling. The *rate of cooling* or the fall of temperature per second is proportional to the excess of temperature above that of the surrounding. Thus the quantity of heat radiated per second by a given surface is proportional to the excess of temperature of the surface above that of the surrounding. This law is true if the excess of temperature is not above 25°C.

Experiment 54. **To verify Newton's law of cooling.**

Apparatus :—A calorimeter, stop watch or stop clock, two ½ degree centigrade thermometers, hot water.

Method. Take a calorimeter and fill it two-third with hot water. Place it on a wooden block so as to expose it to air. Insert a thermometer and a stirrer in it.

Note the temperature of water after every ½ minute and then after an interval of one minute. Keep the water well stirred throughout the experiment.

Note the room temperature by another thermometer.

(*a*) Plot a graph with time along X-axis and temperature along Y-axis (Fig. 70.)

From the graph find the rate of cooling, *viz.*, the fall of temperature during any minute. Find the mean temperature during this minute, and take a number of readings for a few more minute intervals. Find also the excess of mean temperature above the temperature of the surroundings. Tabulate these readings.

(*b*) Draw another graph between excess of mean temperature and rate of cooling (Fig. 71). It will be a *straight line.*

Observations.—

Room temperature=

No. of observation	Time	Temp.

No of. obs.	Mean temp. at one minute interval	Excess of mean temp. above air	Rate of Cooling	Rate of Cooling / Excess of mean temp.

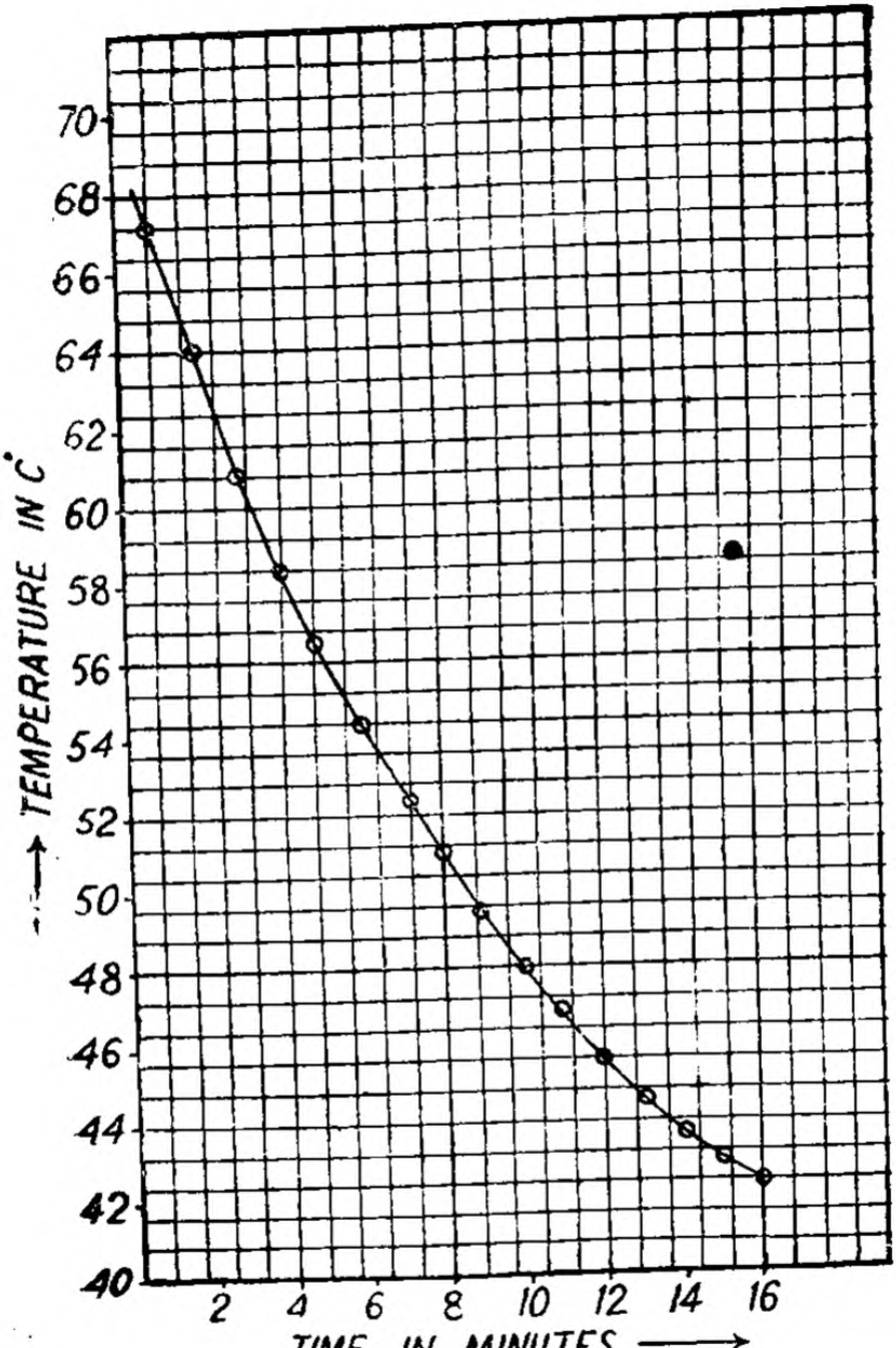


Fig. 70.

A fine book it is

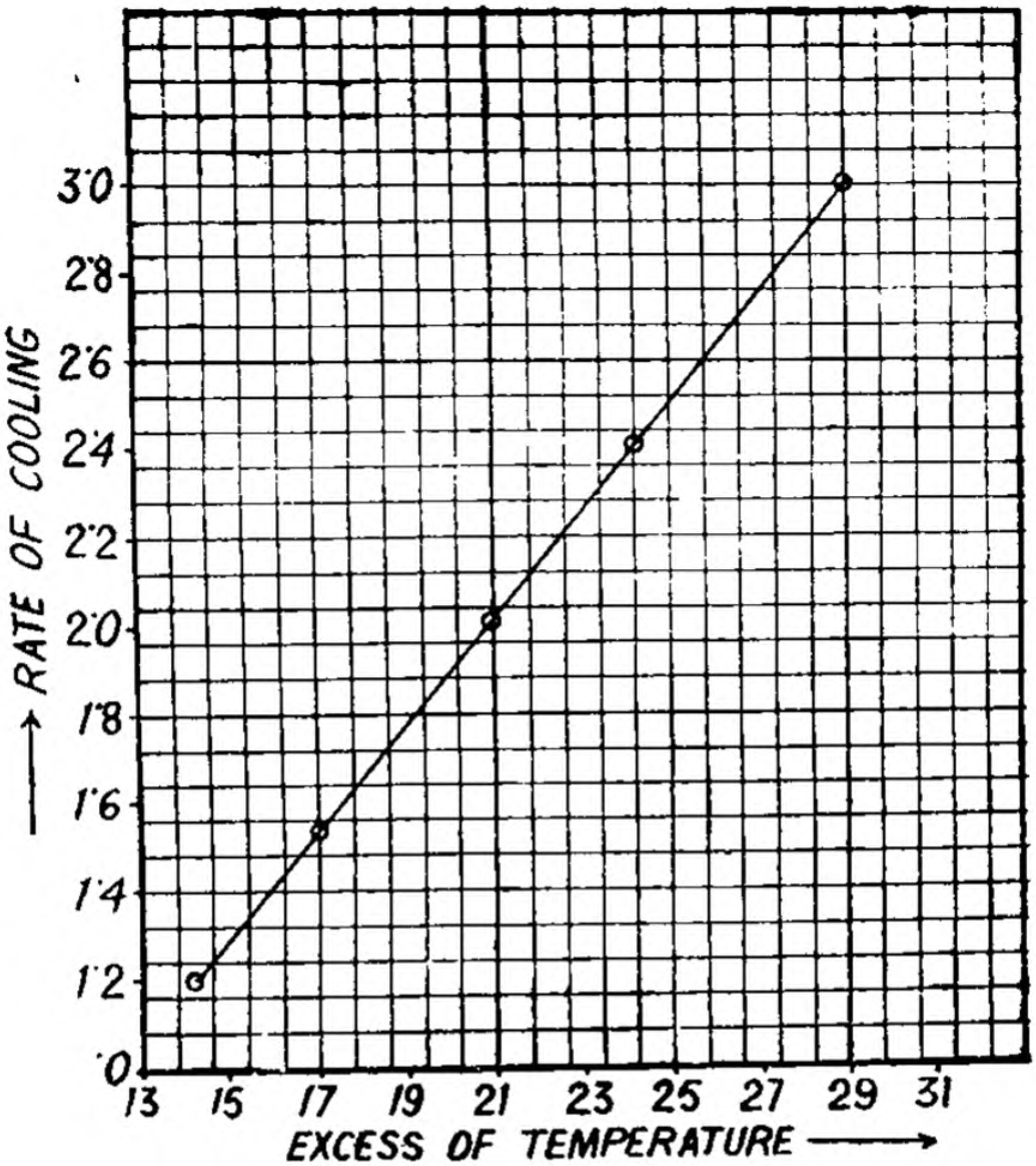


Fig. 71.

Sourcrs of errer. Loss of heat by conduction and convection and evaporation.

Experiment 55. Find the specific heat of oil by the method of cooling.

Apparatus. Two calorimeters, two thermometers, a double walled enclosure to suspend the calorimeters, two graduated cylinders, a stop clock, a water bath, two burners and a flask.

Method. Heat water in a beaker over one burner and oil in a flask in a water bath over the other. Take two calorimeters and weigh them along with the stirrers. Take about 100 c.c. of each hot liquid and pour them into two respective calorimeters, suspended inside the double walled enclosure containing water in the space between the two walls. Note the temperature of each liquid at an interval of one mimute and do it for 30 mimutes. Weigh the two

calorimeters after these have been cooled. Plot two curves on the same graph paper taking time along the X-axis and temperature along the Y-axis.

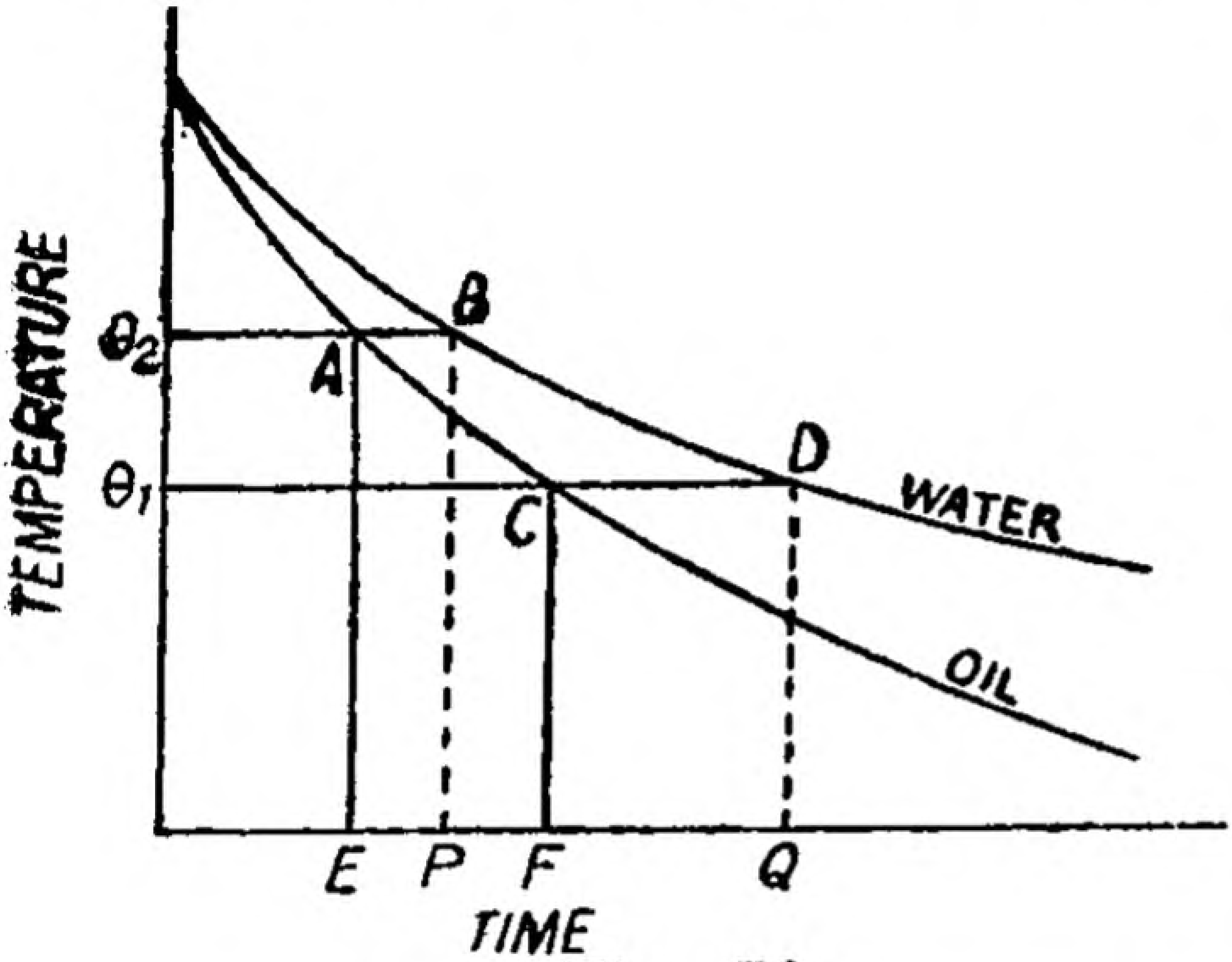


Fig. 72.

From the two curves find the time for each liquid as its temperature falls from θ_2 to θ_1. Let the time in the case of water be t_1 and in the case of oil t_2 minutes. Find the rate of loss of heat in each case and calculate the specific heat of oil by equating them.

Observations.—

Wt. of calorimeter + stirrer $= m_1$

Specific heat of calorimeter and stirrer $=$ S.
Wt. of cal. + stirrer + water $=$
Wt. of water $= M_1$
Quantity of heat lost per minute

$$= (M_1 + m_1 S_1) \frac{\theta_2 - \theta_1}{t_1}$$

Wt. of calorimeter + stirrer $= m_2$
Specific heat of calorimeter and stirrer $= S_2$
Wt of cal. + stirrer + oil $=$
Wt. of oil $= M_2$
Quantity of of heat lost per minute

$$= (M_2 x + m_2 S_2) \frac{\theta_2 - \theta_1}{t_2}$$

where x is the specific heat of oil.

By Newton's law of cooling

$$(M_1 + m_1 S_1) \frac{\theta_2 - \theta_1}{t_1} = (M_2 x + m_2 S_2) \frac{\theta_2 - \theta_1}{t_2}$$

$$x = \left[(M_1 + m_1 S_1) \times \frac{t_2}{t_1} - m_2 S_2 \right] \times \frac{1}{M_2}$$

Tabulate your observations as follows :—

Wt. of calorimeter A $= m_1$ Wt. of calorimeter B $= m_2$

Time	Temp. of water	Time	Temp. of oil

Wt. of cal. + water $= W_1$	Wt. of cal. + oil $= W_2$
M_1 mass of water $= W_1 - m_1$	M_2 mass of oil $= W_2 - m_2$

No.	Range of temp. fall	Time for water	Time for liquid	S.heat of the liquid
1				
2				
3				

It is better to calculate x for each range and then find its mean value.

Precautions. 1. Take equal volumes of the two liquids.

2. Keep the liquids well stirred.

3. Both calorimeters must be of the same size, same material and blackened from outside.

4. Do not bring any hot or cold body near the enclosure otherwise the temperature of the enclosure will change.

5. As far as possible take the initial temperatures to be the same

Sources of error. (1) Loss of heat by conduction and convection, and evaporation.

(2) The temperature of the enclosure may not remain constant.

(3) The surfaces of calorimeters may not be similar.

SOUND

CHAPTER XVII

FREQUENCY OF VIBRATION

Period, Frequency and Wave-length.—Sound is produced by the rapid vibrations of a material body. Like those of a pendulum, these vibrations can be shown to be simple harmonic. They are always produced in elastic bodies, like a tuning fork, a stretched string or a column of air. When a vibrating body is emitting sound, these vibrations are transferred to the air surrounding it in the form of condensations and rarefactions, which when they reach the ear produce the sensation of sound.

The motion of the body from one extreme end to the other and back again to its starting point is called the '**Vibration**' or '**Oscillation**.' Or it is the passage of the vibrating body through its mean position in one direction to its next passage in the same direction. The distance to which it moves on one side from its mean position is its *Amplitude*. The number of vibrations made by a body in one second is its '**Frequency**' and the time of one complete vibration is the '**Time Period**' or the '**Period**.' The frequency and the period of a vibrating body is also the frequency and period of the '**note**' given out by it. The higher the frequency the higher is the '**pitch**' of the note. The period

$$t=\frac{1}{n} \text{ or period } = \frac{1}{\text{frequency}} \quad (1) \qquad \text{Where } n=\text{frequency}$$

$$\text{or} \quad n=\frac{1}{t}, \text{ or frequency } =\frac{1}{\text{period}} \quad (2) \qquad t=\text{period.}$$

Consider a vibrating body to move from one extremity to the other. During the motion it compresses the air adjoining it, which in turn compresses the particles of air next to it and so on. Thus a compression in the air is

produced during one half period of the body, which moves forwards. When it returns on its back-ward journey a rarefaction is similarly produced in the air, which follows the compression and travels through the air during the second half-period. A series of alternate compressions and rarefactions is thus produced in the air, during the vibrations of the body. The distance between 'two consecutive compressions or between a 'crest' and the next 'crest' or between two neighbouring troughs is called a 'wave-length.' A wave-length is, therefore, the distance through which, a compression or rarefaction travels in the time period.

$\lambda = vt$ (3)

or from Equation (1) $t = \frac{1}{n}$

$\lambda = v \times \frac{1}{n}$

or $v = n\lambda$ (4)

If
v=velocity with which waves travel.
λ=wave-length.
t=period.

Tuning Fork.—It is a U-shaped bar of steel, with a side bar at the bend to hold or to fix it on a sounding box or board. The note emitted by a tuning fork when struck with a rubber hammer or against a soft pad is the simplest possible, hence it is very commonly used in the laboratory to produce a note of any desired frequency. This note is taken to be a standard one and the notes emitted by other bodies are compared with it by 'tuning'—hence its name '**tuning fork**.' The frequency of the tuning fork is generally marked on it. This is sometimes shown by letters of the alphabet. In the middle Dia-tonic Scale the frequencies corresponding to these letters are :—

C	D	E	F	G	A	B	C
256	288	320	341	584	427	480	512

Measurement of Frequency :—

(*a*) By the method of Beats.

If two tuning forks, of nearly equal frequencies, mounted on sound boxes be struck one after the other the sound heard will alternately rise and fall. These are called 'Beats'. The number of beats heard per second will be equal to the difference of their frequencies. This can easily be shown to

be the case. Let two tuning forks have frequencies equal to 8 and 9. Let the waves produced be represented by the two displacement curves, in thick and dotted lines as shown in figure 73. (A) shows the component curves, and their resultant is shown in Fig. (B). At C the two waves are in the same 'phase' *i.e.*, a crest coincides with a crest and a trough with a trough. The resultant curve at this point will have the largest amplitude. As the waves progress, one being shorter than the other, they soon become out of step at D, *i.e.*. at a distance from C, covered in half the period, one gains above the other half a wave-length and the crest of one is super-imposed on the trough of the other. The two waves destroy or neutralise one another and the resultant curve has a negligible amplitude at the point. This is repeated after regular intervals. In one second two such points of great or small amplitude will pass the ear of the observer or the sound heard will rise or fall once in one second or there will be one beat heard per second. Similarly if the frequency difference is 4, there will be 4 beats per second, and so on.

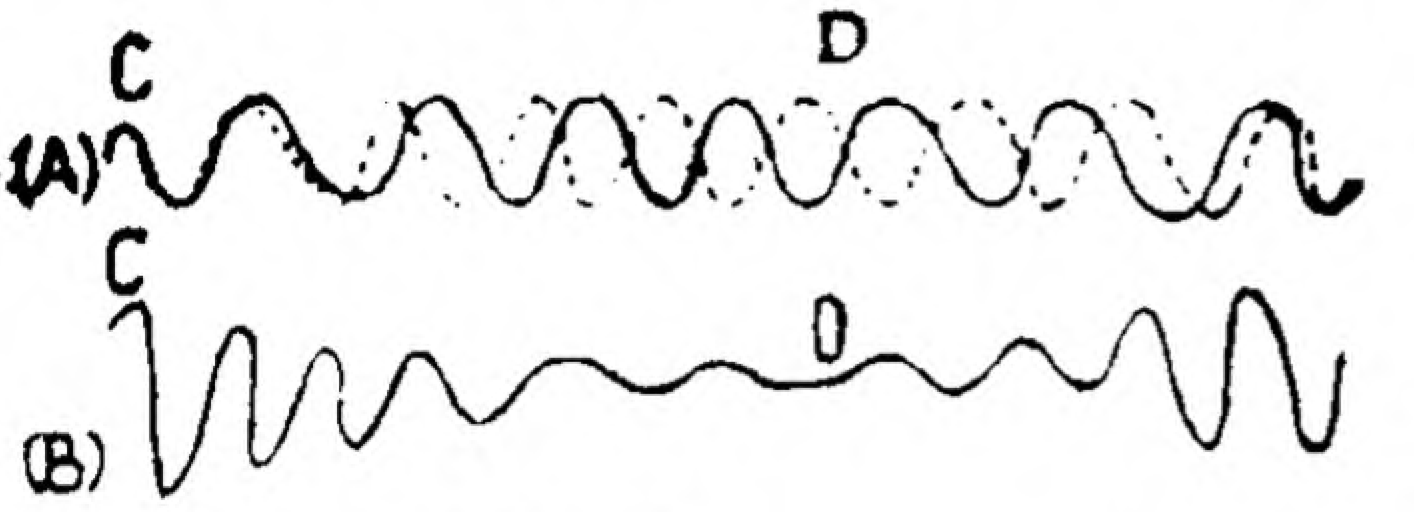


Fig. 73.

The phenomenon of 'beat' gives us a very convenient method of measuring the frequency of a tuning fork by sounding it along with another of nearly equal frequency, which is known. The time in which a certain number of beats are heard is determined and the number of beats per second is m and n=known frequency, the unknown frequency will be $n+m$ or $n-m$. To find whether the plus or the minus sign is to be used, a prong of the tuning fork whose frequency is to be determined is loaded with a little wax or a small load fixed by a screw as shown in figure. This reduces its frequency. If the forks are struck again and the number of beats increases, its original frequency without the load was lower than that of the other and hence its frequency will be $n-m$. But if the beats heard per second decrease, its frequency in the unloaded condition was origi-

nally above that of the other, *i.e.*, $n+m$*. We shall now describe below the method of determining the frequency of a tuning fork.

Experiment 56.—**To determine the frequency of a tuning fork by the method of 'beats' with another of known frequency.**

Apparatus.—Two tuning forks of nearly equal frequencies mounted on sound boxes, one of them being known; a rubber pad, hammer and a stop watch.

Method.—The tuning forks being placed with their sound-boxes facing one another as shown in Fig. 74, they are struck with the hammer one after the other, a certain number of beats are heard and the time noted. This is repeated several times and the mean for the

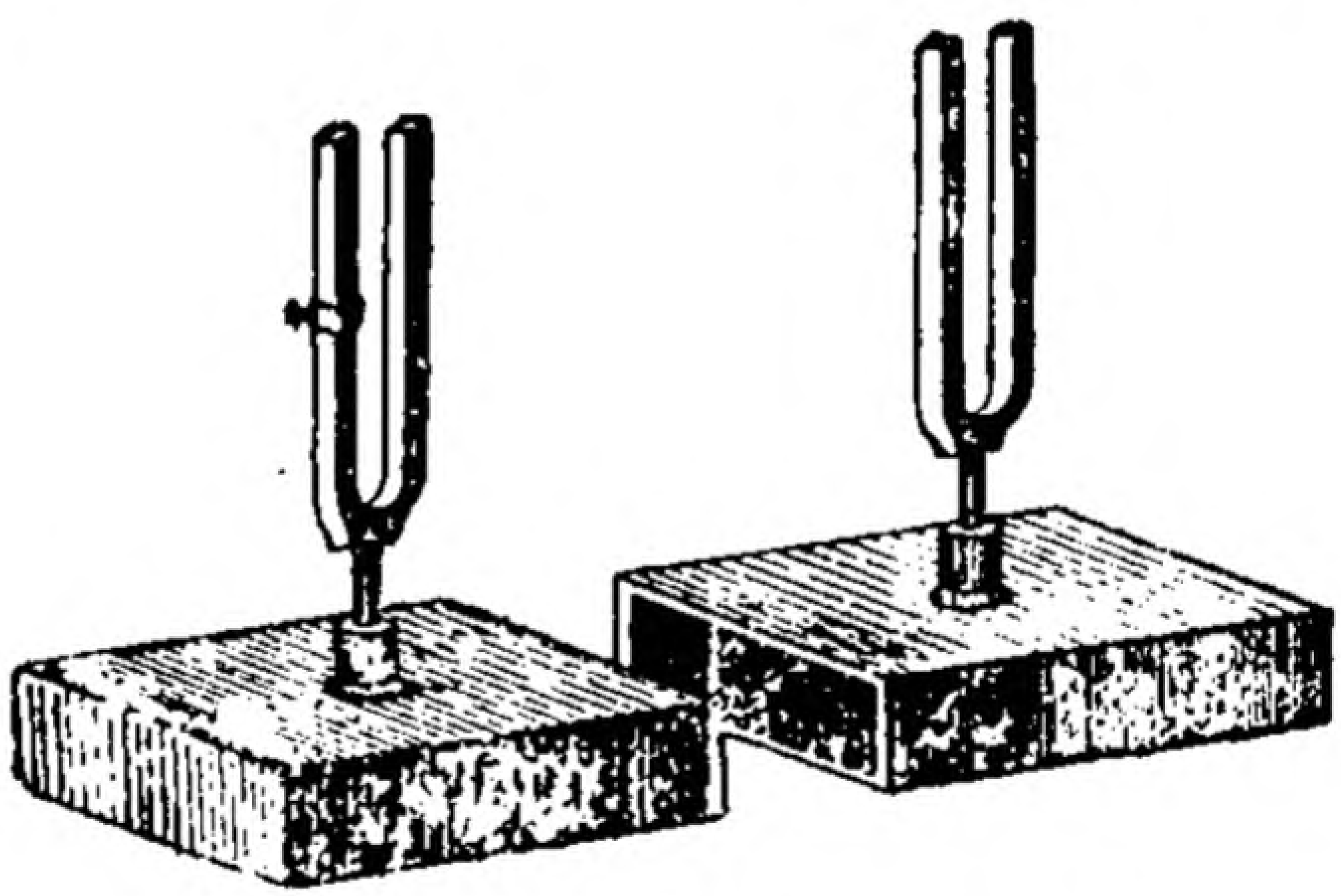


Fig. 74.

beats heard per second calculated. The tuning fork with the unknown frequency is loaded near its bend and the beats and the corresponding times noted again. If the number of beats increases the number of beats heard per second before loading is subtracted from the known frequency. If they decrease it is added to it. The sum or the difference gives the unknown frequency of the fork.

* *Note*—The load should not be too great. For if the frequency to be determined were above the known frequency, the load may decrease it too much below that of the other, and the beats heard instead of decreasing may actually increase.

Observations :

No. of observations.	No. of beats.	Time in sec.	Beats per sec.	Mean
1.				
2.				
3.				
4.				
5.				$=m$ (say)

The known frequency $=n$ (say)

On loading the fork the beats increase (or decrease).

The required frequency $=n-m$ or $(n+m)$.

Precautions : 1. The unknown frequency should not differ by more than 4 from the known one, otherwise the beats will be too rapid to count.

2. The prong of the fork, with unknown frequency should not be loaded too heavily.

3. Time should be recorded to $\frac{1}{5}$ of a second.

CHAPTER XVIII

RESONANCE COLUMNS

Measurement of Velocity and Wave-length.—A tuning fork is held over the open mouth of a tube closed at the other end, and if the length of the tube be adjusted a position is obtained where the sound emitted by the fork is reinforced by the vibrations of the air column which vibrates in sympathy with the tuning fork. This is called Resonance, and the air in the tube, the **Resonance Column**.

The simplest form of apparatus used to illustrate this phenomenon is shown in figure. The lower prong of the tuning fork as it moves down produces a compression in the air, which travels down the tube and on reflection at the surface of water as compression arrives at the open end. If at this instant the prong has completed half the vibration and is on the point of moving upward it will be helped by the arrival of the compression wave and a greater rarefaction is produced, due to both the upward motion of the prong and the reflection of the compression wave as a wave of rarefaction at the open end. This wave of rarefaction now moves down and if it arrives at the open end as rarefaction at the instant when the tuning fork has completed one vibration and is about to produce a compression, the two will again help each other. The period of vibration of air column will then be the same as that of the tuning fork, and the note emitted by the column of air will have frequency equal to that of the fork, and the note heard will be louder.

During the time that the tuning fork executes one complete vibration, the wave will have travelled the length of the tube down and up four times, twice as a compression and twice as a rarefaction. But the distance travelled by

the wave in one complete vibration of the tuning fork is one wave-length, hence

$$\left.\begin{array}{l}\lambda=4l_1\\ \text{or } l_1=\tfrac{1}{4}\lambda\end{array}\right.\quad(1)\quad\left\{\begin{array}{l}\text{If}\\ \lambda=\text{wave-length,}\\ l_1=\text{length of resonance tube.}\end{array}\right.$$

This is called the first resonance position.

A second position of resonance is obtained if the length of the tube be increased by one-half wave length. By the time that a compression takes to move down and up the tube once, the tuning fork completes one and a half vibrations, and at the instant, the two are in a position to reinforce each other, and the tube resounds. Twice the length of the tube will then be equal to one and a half wave lengths. Thus if l_2=length of the tube, in the second position of resonance

$$l_2=\tfrac{3}{4}\lambda. \qquad (2)$$

End Correction of the tube.—The reflection of the waves, however, does not take place exactly in the place of the open end, but a little beyond it. The effective length of the resonance column is, therefore, increased by an amount depending upon the diameter of the tube. This is called the "**Correction for the open-end**" or only the "**End Correction.**" If the diameter of the tube be$=d$ cms., this end correction is found to be nearly$=\cdot 3d$ cms. This can also be determined experimentally thus :

Let c be=the end correction.

Allowing for this in equations (1) and (2), we get—

$$l_1+c=\tfrac{1}{4}\lambda \qquad (3)$$

$$\text{and } l_2+c=\tfrac{3}{4}\lambda \qquad (4)$$

Subtracting (3) from (4) we get :—

$$l_2-l_1=\tfrac{1}{2}\lambda \text{ or } \frac{l_2-l_1}{2}=\tfrac{1}{4}\lambda \qquad (5)$$

From (3) and (5) we get

$$\frac{l_2-l_1}{2}=\frac{\lambda}{4}=l_1+c$$

$$\therefore c=\frac{l_2-l_1}{2}-l_1=\frac{l_2-3l_1}{2} \qquad (6)$$

The values of l_2 and l_1 are obtained from the two positions of the resonance, and the end correction determined from equation (6).

Measurement of Wave length—The end correction is calculated from the internal diameter of the tube measured by calipers, and this is added to the length of the tube l_1 obtained from the first position of resonance. The wave-length will then be from equation (3)

$$\lambda=4(l_1+c) \qquad (7)$$

Or, if the tube is long enough to get the second resonance position the value is obtained from equation (5)

$$\lambda=2(l_2-l_1), \qquad (8)$$

Measurement of Velocity of Sound-waves.—It has been shown already that

$v=n\lambda$
or $v=n\times 4(l_1+c)$
from equation (7)

If
v=velocity.
n=frequency.
λ =wave-length.

or $v=n\times 2(l_2-l_1)$.
from equation (8)

If velocity at the room temperature be known, the frequency of the tuning fork can be determined from the above equations.

Experiment 57.—**To determine** (*a*) **the velocity of sound in moist air** (*b*) **the frequency of a tuning fork and** (*c*) **the end correction, by the resonance column.**

Apparatus.—Resonance tube, a tuning fork, a cushion pad, plumb line, a set-square and a vernier calipers.

Description of Resonance tube.— It consists of a glass tube whose lower end is connected with a water reservoir by means of rubber tubing. The level of water in the tube can be changed by moving the reservoir up or down along a rod. By means of a pinch cock the communication of water between the tube and reservoir can be established or broken.

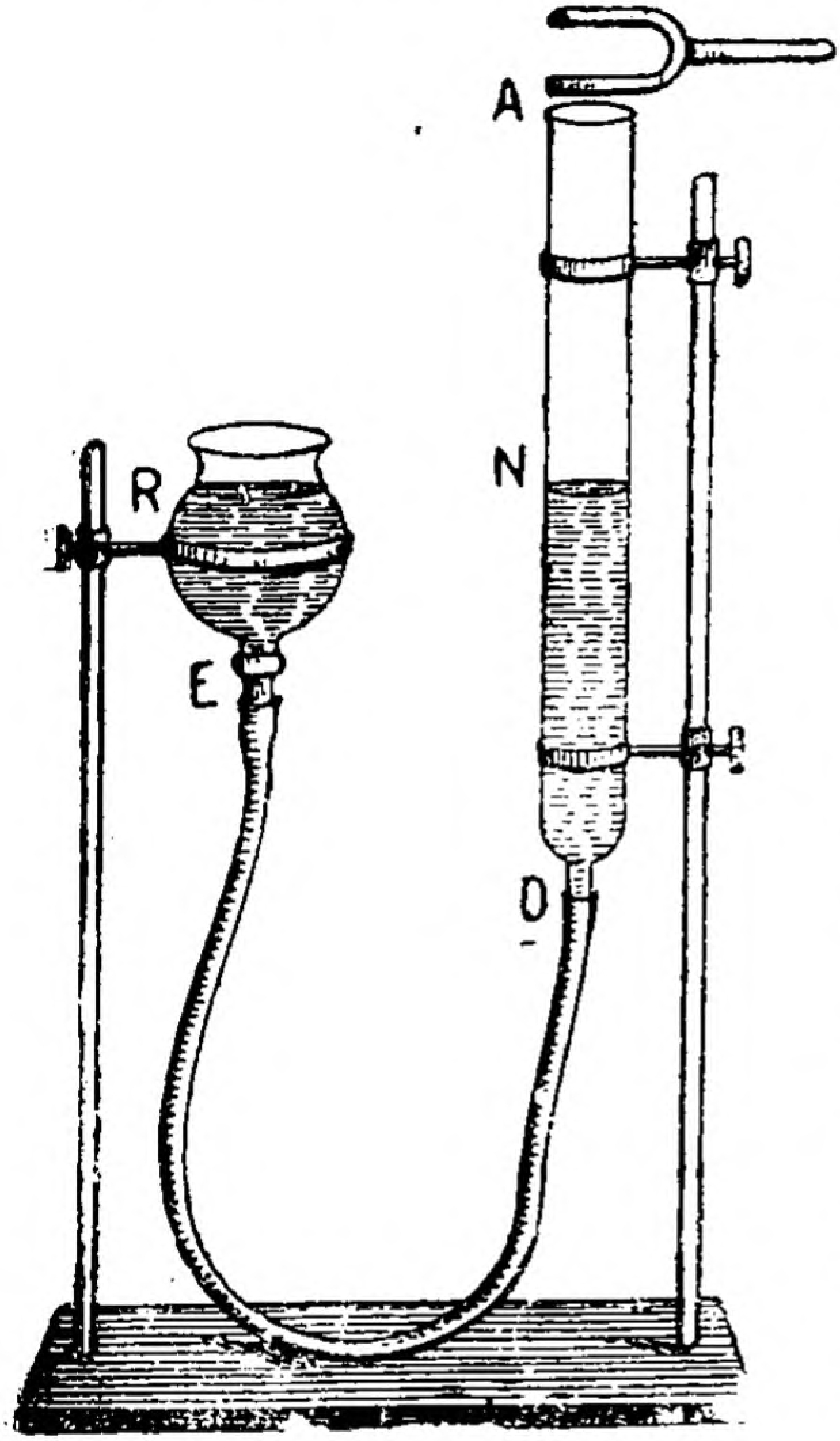


Fig. 75.

Method.—Raise the level of water to the highest point in the tube by raising the reservoir as shown in figure 75. Lower the reservoir of water and clamp it. Take a tuning fork and set it vibrating by striking it against a rubber cork and place it over the open end of the tube. By means of the pinch-cock bring down the level of water in the tubé and adjust a position when a point of maximum loudness is obtained. Now adjust the level of water a little higher than this and again place the vibrating tuning fork over the open end of the tube. Allow the level of water to fall gradually till we get a sharp point. Note the length of air column. Find the mean of a few observations.

In the same way, find the second position of resonance and find the mean of five or six observations.

Try the experiment with two tuning forks of different frequencies.

Observations :

Frequency of the tuning forks A, B =
Temperature of the room = °C.
Diameter of the tube in transverse positions =(1) ..(2)...
Mean=......cms.

No. of observations.	open end.	First Resonance.		Second Resonance	
		Water level.	Resonance column (l_1)	Water level.	Resonance column (l_2)
	cms.	cms.	cms.	cms.	cms.
A 1					
2					
3					
B 4					
5					
6					
			Mean=...		Mean=...

Calculations and Results.

End correction=$\cdot 3\times$diameter=c cms. (say).

1. Velocity. Let **velocity** at room temperature $=v$ cms. per sec.

(*a*) From first resonance position

$$v=n\times\lambda$$
$$=4n(l_1+c) \text{ cms. per sec. from equation (7)}$$
$$=4n(l_1+c)\times\cdot 01 \text{ metres per sec.}$$

(*b*) From 1st and 2nd resonance positions

$$v=n\times\lambda$$
$$=2n(l_2-l_1) \text{ from equation (8).}$$
$$=2n(l_2-l_1) \text{metres per sec.}$$

2. **For end-correction**, use the formula,

$$c=\frac{(l_2-l_1)}{2}-l_1=\frac{l_2-3l_1}{2}.$$

3. **Frequency** n can be similarly determined if velocity at room temperature be known.

Precautions : 1. The tube and the scale kept vertical, and set squares used for taking readings.

2. Reading at the water level taken at the lower surface, by keeping eyes at the same level.

3. Three readings each for the column taken, when increasing the length and when decreasing it.

4. Temperature of the room recorded and the velocity at 0°C calculated as given below.

5. Velocity is expressed in metres per second. When calculating frequency, velocity is expressed in cms. per second.

6. The length of the tube should be at least three-fourth the wave-length of the note emitted by the tuning-fork. For this purpose tuning forks of frequencies 480 and 512 are generally used.

(1) Velocity of sound at 0°C.

Velocity of sound at 0°C is calculated from that at the room temperature thus :—

$$v=v_0+61\times t \quad (1) \begin{cases} \text{Let} \\ v=\text{velocity in cms. at temp. } t^\circ\text{C.} \\ v_0= \quad ,, \qquad ,, \qquad ,, \quad 0^\circ\text{C.} \end{cases}$$

Equation (1) is applicable only when the room temperature is not very high. For high temperatures the following formula should be applied :

$$\frac{v}{v_0}=\sqrt{\frac{T}{T_0}} \quad \begin{cases} \text{Where} \\ T=\text{temperature of room on absolute scale.} \\ T_0=\text{temp. corresponding to } 0^\circ\text{C.} \end{cases}$$

$$\text{or} \quad \frac{v}{v_0}=\sqrt{\frac{273+t}{273}} \quad \begin{cases} \text{Where} \\ t=\text{temp. of room in }^\circ\text{C.} \end{cases}$$

$$\text{or} \quad v=v_0\left(1+\frac{1}{273}\times t\right)^{\frac{1}{2}}$$

$$=v_0\left(1+\frac{1}{546}\times t\right) \quad \text{(approximately).}$$

Correction for 1°C is

$$=\frac{v_0}{546}\times 1 \quad \left[\begin{array}{l}\text{If } t=1\cdot0°\text{C} \\ v_0=331 \text{ metres per sec.}\end{array}\right.$$

$$=\frac{33100}{546}=61 \text{ cms. per sec. (nearly)}$$

(2) Change in **atmospheric pressure** does not change the velocity of sound. For in

$$v=\sqrt{\frac{\gamma P}{d}}$$

the ratio $\frac{P}{d}$ remains constant (Boyle's Law).

v=velocity.
γ=ratio of specific heats of a gas =constant.
P=pressure.
d=density.

(3) Presence of **moisture** in the air increases the velocity but not to an appreciable extent to be taken note of.

Exercise :—Compare the frequencies of two tuning forks.

[**Hint**. With the help of one of the two tuning forks (say **A**) determine the wave length of the note produced by it.

$\lambda_A=2(l_2-l_1)$ where l_1 and l_2 are the lengths of the two resonance columns.

Similarly find λ_B for the note produced by the second tuning fork.

$\lambda_B=2(l'_2-l'_1)$ where l'_1 and l'_2 are the lengths of the two positions of resonance. Frequencies are inversely proportional to the wave lengths.

$$\frac{n_1}{n_2}=\frac{\lambda_B}{\lambda_A}=\frac{2(l'_2-l'_1)}{2(l_2-l_1)}=\frac{(l'_2-l'_1)}{(l_2-l_1)}\Bigg].$$

LIGHT

GENERAL DIRECTIONS TO BE OBSERVED IN OPTICAL EXPERIMENTS

1. *Neat work is needed in graphical experiments on light.* The student should, therefore, be particularly careful of his *pencil* which should be *well sharpened.* As far as possible, use a hard drawing pencil.

2. A drawing board should be used wherever needed. The paper should be fixed to the drawing board and not to the working table with drawing pins.

3. In *photometric experiments* when comparing two sources of different colours, ignore the difference in colour, and judge the two shadows by their depth.

4. In *pin experiments* while fixing pins see that the distance between two pins is not less than 10 cms. Draw small circles round the pin holes before removing the pins, and draw lines accurately through the pin holes.

5. See that no part of the apparatus is shaky. The uprights to be used in experiments on focal lengths should not be shaky.

6. In experiments on the determination of focal lengths of mirrors and lenses, find *index corrections* rather than *index errors*. This saves lot of botheration.

7. Before commencing *experiments* on *parallax*, try to understand clearly what is meant by *parallax*. While trying to remove parallax, the image and the pin locating it should be in a line and their tips should touch each other. The eye should be moved sideways when the pins are vertical, and up and down when the pins are horizontal.

Remember that out of the two objects that which moves in the direction of the eye is farther of the two.

8. While determining the focal length of a lens or a mirror by the *method of parallax*, the eye should be placed

at least 30 cms. behind the needle with which image is being located. It must not be placed close to it.

9. Graphs should be drawn whenever possible. The following graphs are very important :—

(*a*) Graph showing the relation between *Sin i* and *Sin r* for a rectangular glass block.

(*b*) Graph showing the relation between angles of incidence and angles of deviation for a prism, and determination of the angle of minimum deviation from the graph.

(*c*) Graph showing the relation between u and v and between $\frac{1}{u}$ and $\frac{1}{v}$ for a concave mirror and the determination of focal length of the mirror from the graph.

(*d*) Graph showing the same relation as mentioned above in *c* for a convex lens.

10. Make liberal use of logarithmic tables for calculations.

CHAPTER XIX

PHOTOMETRY

Photometry is the measurement or comparison of illuminating powers of different sources of light.

Intensity of illumination is the amount of light received per unit area of a surface placed perpendicular to the rays of light in one second.

Illuminating power or luminosity of a source is the total amount of light that it emits in unit time.

The Law of Inverse Squares—The intensity of illumination of a point source of light varies inversely as the square of the distance of the surface from the source.

$$I = \frac{L}{d^2}$$

where I is the intensity of illumination, L illuminating power of the source, and d the distance of the source from the surface.

Standard Candle.—It is a sperm candle, $\frac{7}{8}$ inch in diameter, $\frac{1}{6}$th of a pound in weight, and burns at the rate of 120 grains per hour.

It is the unit in terms of which illuminating power is measured.

When we say that an Osram lamp is of 32 candle power, all that we mean by it is that it provides as much light as is emitted by 32 standard candles.

The efficiency of a lamp is the ratio of its candle power to the energy consumed by it in unit time. The energy consumed is measured in watts.

The Principle underlying Photometry.—In order to compare the illuminating powers of two sources of light, we should adjust the distance of the two sources from a screen such that these produce the same intensity of illumination of it. The distance of each source from the given

surface is measured. Let L_1 and L_2 represent the illuminating powers of two sources and d_1 and d_2 the distances of the two sources from the screen where these produce the same intensity of illumination.

$$I_1 = \frac{L_1}{d_1^2} \qquad I_2 = \frac{L_2}{d_2^2}$$

$$\therefore \quad \frac{L_1}{d_1^2} = \frac{L_2}{d_2^2} \qquad \text{or} \qquad \frac{L_1}{L_2} = \frac{d_1^2}{d_2^2}.$$

The illuminating powers of two sources of light are directly proportional to the squares of their distances from the given surface at which they produce the same intensity of illumination.

Photometers are instruments by which we compare the illuminating powers of two sources of light.

Different types of photometers.—(*a*) Rumford (*b*) Bunsen's Grease spot (*c*) Paraffin Block.

Measurement of intensity of illumination.—The intensity of illumination is expressed in terms of **foot-candles.**

A foot candle is the illumination produced on a surface at a distance of one foot by a standard candle.

$$\textbf{Illumination (foot candles)} = \frac{\textbf{Candle power}}{\textbf{Distance squared (ft.)}^2}$$

Thus a lamp of 16 C.P. will produce at a distance of 2 ft. an illumination equal to 16/4 = 4 foot candles. A lamp of 50 C. P. will produce at a distance of 5 feet an illumination of 50/25 = 2 foot-candles.

Foot-candle Meter.—It is an instrument for measuring the intensity of illumination directly.

It consists of a row of translucent spots which are illuminated by an electric lamp that is within the case at one end. Below each spot the intensity in terms of foot-candles is given. In order to be sure that the lamp burns at the same intensity, the instrument is provided with a *rheostat* in series with a battery,

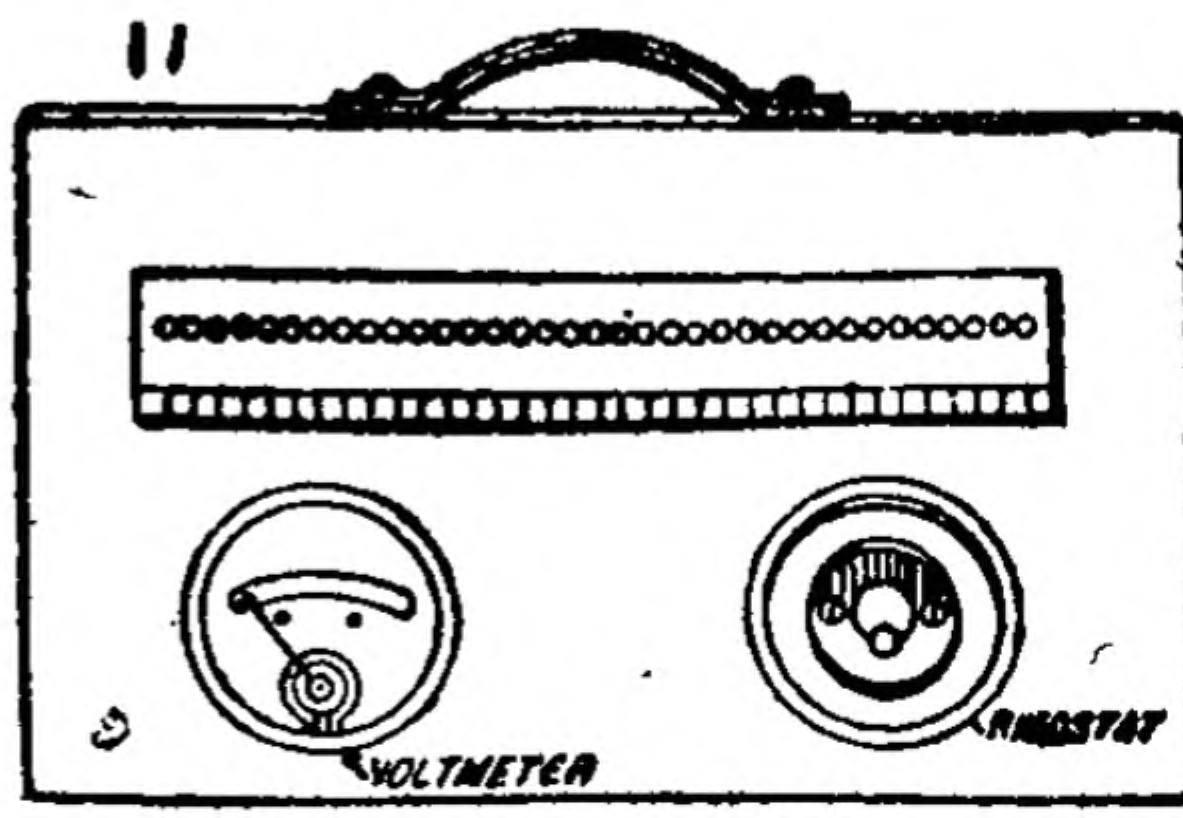


Fig. 76.

and a *voltmeter* for measuring the voltage supplied to the lamp. Thus in order to measure the illumination of a surface, adjust the rheostat until the voltmeter shows that the lamp is getting the required voltage, and then out of the row of translucent spots select that particular spot which is of the same brightness as the given surface whose illumination is to be determined. The intensity of illumination below the spot is then read from the instrument.

One modern foot candle meter consists of a photo-electric cell and a galvanometer. The light is allowed to fall on the photo-electric cell and a current of electricity is produced which is directly proportional to the quantity of light falling on the cell. The scale of the galvanometer is calibraed so as to read in foot-candles. In order to cover high and low ranges of the intensity of illumination, there are two or three scales attached to the instrument.

Experiment 58.—**To compare the illuminating powers of two sources of light by means of Rumford's shadow photometer.**

Apparatus.—Rumford's photometer, two electric lamps of different candle power, a metre-stick.

Method.—Rumford's photometer consists of a rod in front of a ground glass screen.

Place the two sources of light at different distances from the screen and let the two shadows of the rod lie side by side and keeping the distance of one source fixed, adjust the other till the two shadows are of equal depth.

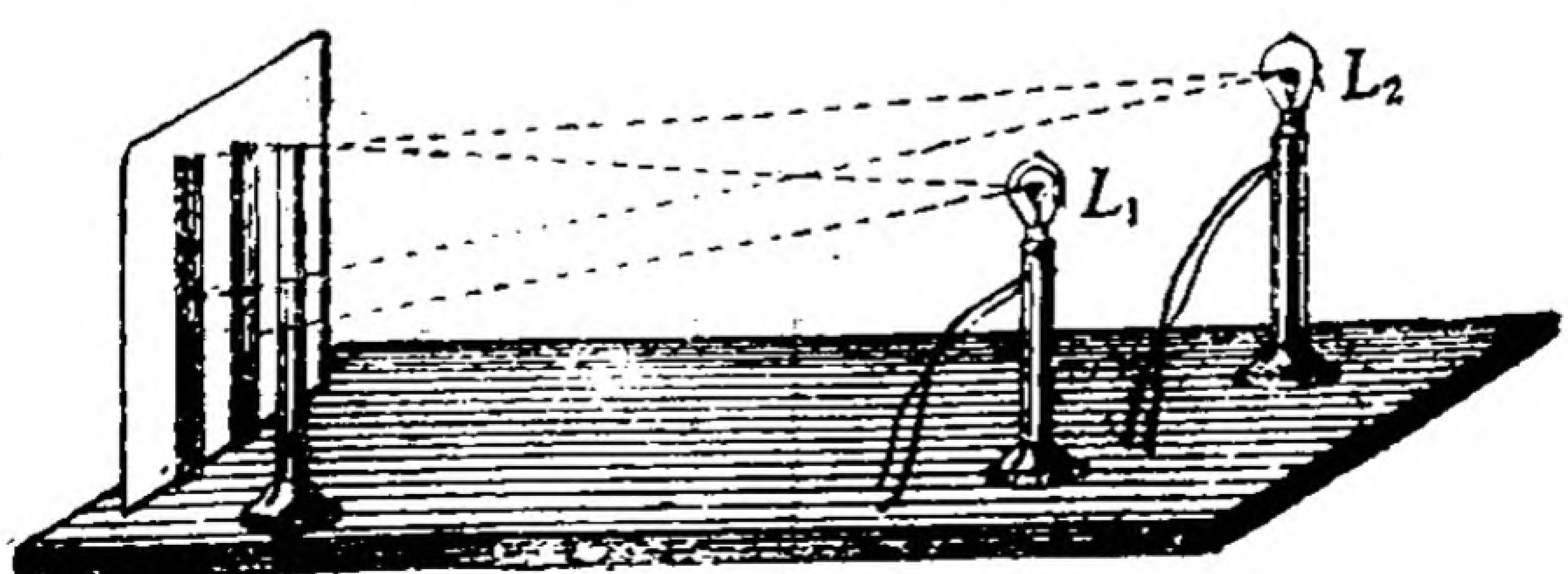


Fig. 77.

Each source casts a shadow of the rod on the screen. The shadow cast by L_1 is illuminated by L_2 and the shadow cast by L_2 is illuminated by L_1. When the two shadows

are of equal depth, the intensity of illumination is the same. Always look at the shadows from behind the ground glass screen. Let d_1 be the distance of L_1 and d_2 the distance of L_2 from the ground-glass screen, then

$$\frac{L_1}{L_2}=\frac{d_1^2}{d_2^2}.$$

By changing the distance d_1 of the source L_1 adjust the distance d_2 of the source L_2 so that the intensity of illumination becomes the same. Make a few trials in this way.

Record thus :—

No. of observations.	Distance of L_1 from screen d_1	Distance of L_2 from screen d_2	$\frac{L_1}{L_2}=\frac{d_1^2}{d_2^2}.$
1.			
2			
3.			
4.			

Precautions—1. If the two sources are of different colours, ignore the colours and judge the shadows by their depth.

2. The distance should always be measured from the screen and not from the rod.

3. The experiment should be tried in a dark room. In the absence of such a room select the darkest part of the laboratory for such work.

Sources of error :—If a dark room be not available, it will be difficult to take accurate observations due to extra light falling on the screen.

Note.—(*a*) If out of the two sources one be a standard candle, the luminosity of the other source can be expressed in terms of candle power.

$$\frac{L_1}{L_2}=\frac{d_1^2}{d_2^2}.$$

Let L_2 be a standard candle, then $L_1 = I \times \frac{d_1^2}{d_2^2}$.

(*b*) If a ready-made photometer be not available place a retort stand in front of a screen.

Grease-spot Photometer :—Grease-spot photometer consists of a white paper screen in the centre of which is a grease-spot which transmits light freely. The best form of the grease-spot photometer is shown in Fig. 78. The two mirrors m_1 and m_2 enable us to see the two sides of the grease-spot at the same time. The photometer is placed between the two sources to be compared. If the screen is illuminated more on one side than on the other, there appears on that side a dark spot in the centre of a bright surface, and on the other side a bright spot in the centre of a dark surface. If both the sides are equally illuminated, the spot disappears or at least appears equally bright from both sides.

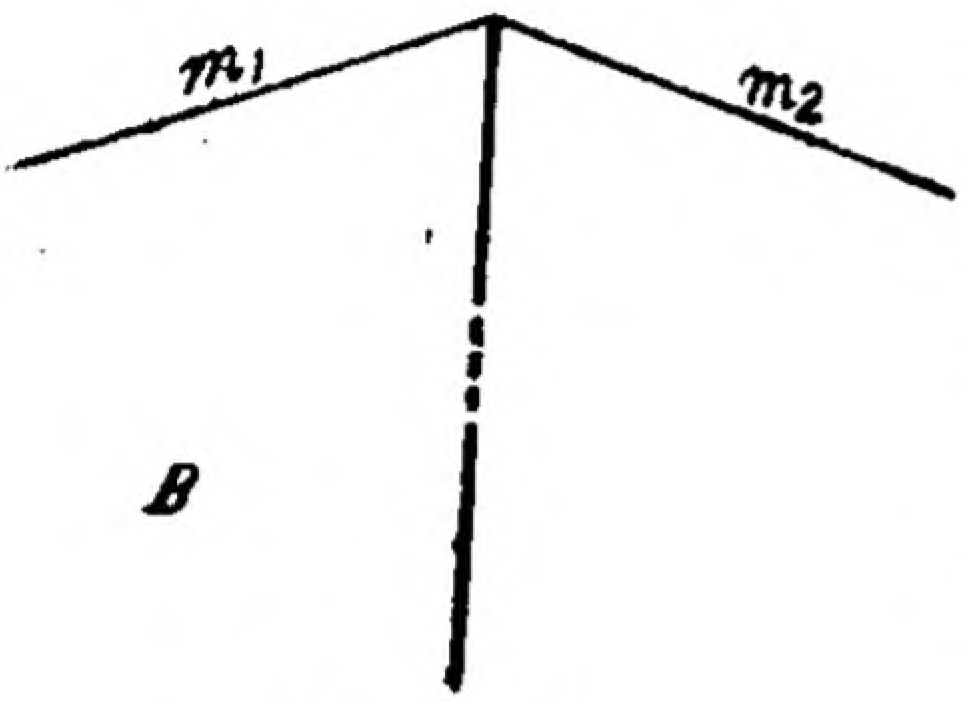


Fig. 78.

Experiment 59.—**To compare the illuminating powers of two sources of light by Bunsen's grease spot photometer.**

Apparatus.—Bunsen's grease spot photometer, the two sources of light (two electric lamps of different candle power), a metre-stick.

Method.—Place the two electric lamps on opposite side of the grease spot and adjust their distances till

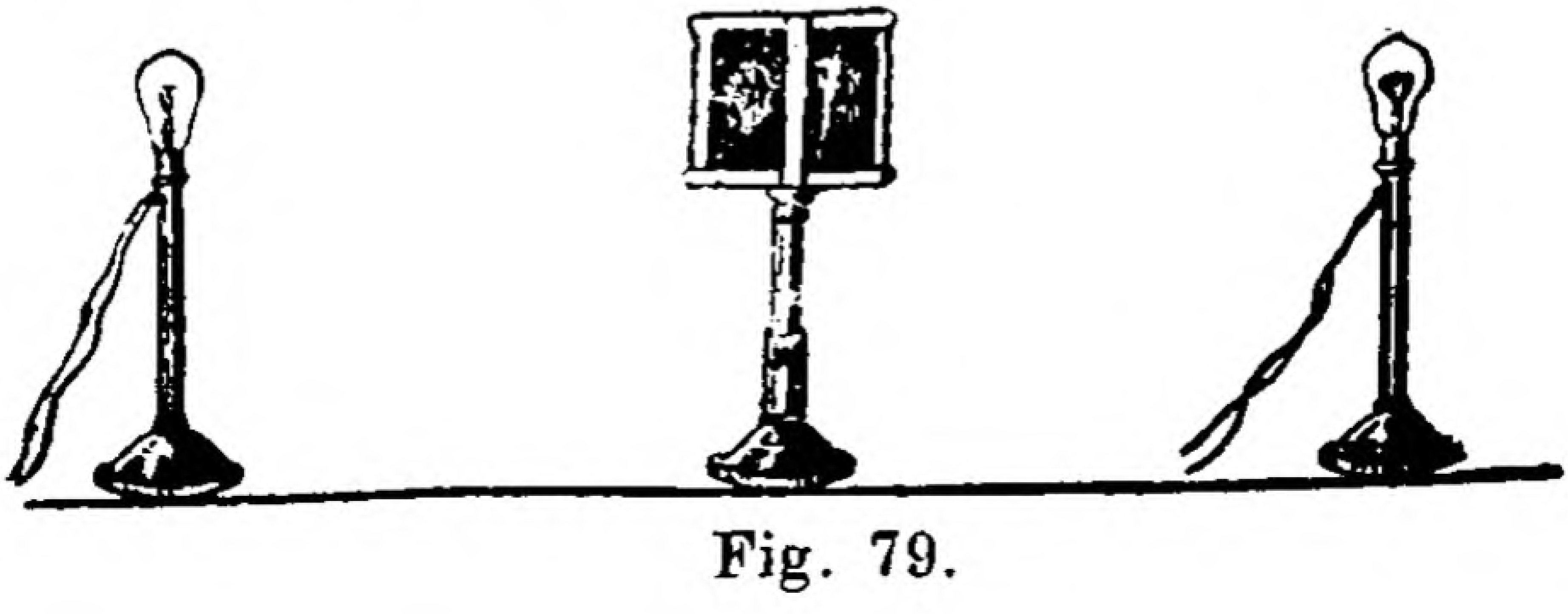


Fig. 79.

you see that that two sides of the grease spot are equally bright. The mirror will enable you to see the two sides of the grease spot simultaneously and judge when both are equally bright. Measure the distance of each source from the grease spot. Let d_1 and d_2 be the distances of the two sources from the grease spot.

$$\frac{L_1}{L_2}=\frac{d_1^2}{d_2^2}.$$

Take a few readings and record thus :—

No. of observations.	Distance of L_1 from the spot. d_1	Distance of L_2 from the spot. d_2	$\frac{L_1}{L_2}=\frac{d_1^2}{d_2^2}$
1.			
2.			
3.			
4.			
			mean=

Experiment 60.—**To verify the law of inverse squares with the help of a photometer.**

Apparatus. Grease spot photometer, candles, metre rod

Method.- Place a candle on one side of the grease spot photometer and a holder containing two candles on its other side. Keeping the single candle at a fixed distance, adjust the distance of the two candles so that the grease spot appears equally bright from both sides. Measure the distances of the sources from the grease spot accurately. Repeat the observation. Again try the experiment by using three candles instead of two and then four candles and so on, while there is a single candle on the other side of the grease spot.

Let L_1 and L_2 stand for the luminosities of the sources and d_1 and d_2 their respective distances from the grease spot

as shown in Fig. 80.

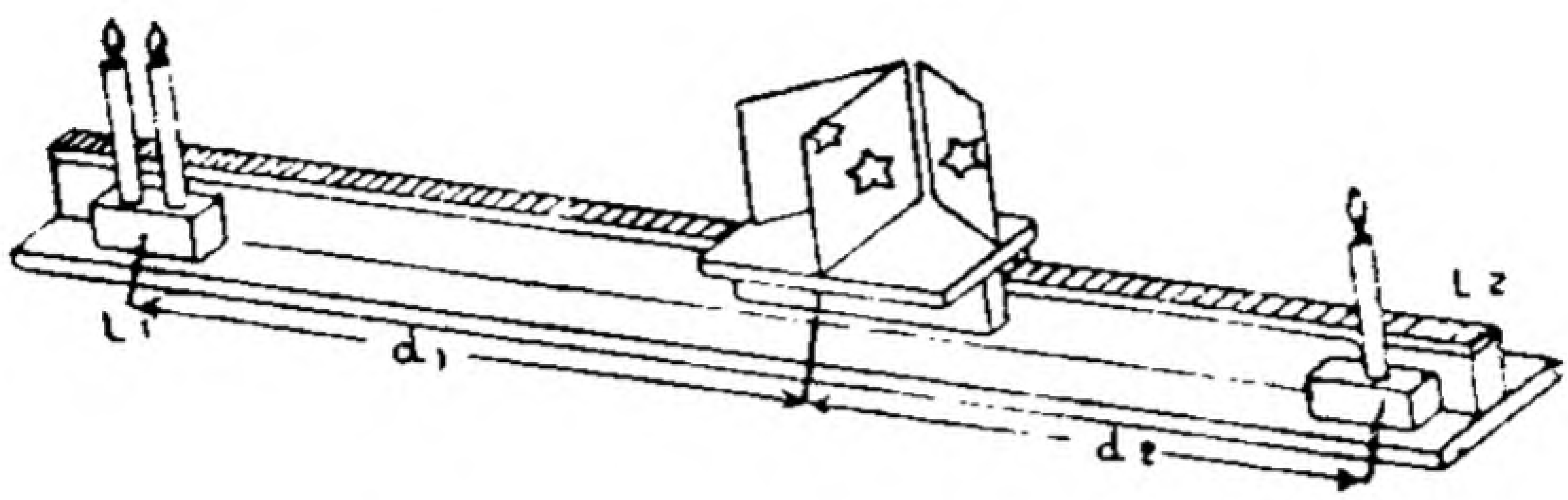


Fig. 80.

Record your observations in a tabular form :—

L_1 (candles used)	L_2 (candle)	$\frac{L_1}{L_2}$	d_1	d_2	$\left(\frac{d_1}{d_2}\right)^2$	Mean $\left(\frac{d_1}{d_2}\right)^2$
2	1	2				
3	1	3				
4	1	4				
5	1	5				

Compare the ratios L_1/L_2 and $(d_1/d_2)^2$. If these are equal, the law of inverse squares is proved.

Since the two sides of the grease spot are equally illuminated, so the intensity of illumination L_1/d_1^2 due to one source must be equal to the intensity of illumination L_2/d_2^2 due to other source or $L_1/L_2=(d_1/d_2)^2$.

In this case, the ratio L_1/L_2 is known. If L_1/L_2 is equal to 2, then d_1^2/d_2^2 must be equal to 2; if L_1/L_2 is equal to 3, then d_1^2/d_2^2 must be equal to 3 and so on.

Paraffin Block Photometer. It consists of two blocks of paraffin each one inch square and one fourth of an inch in thickness with a tin-foil partition between the two. The two blocks are enclosed in a box the sides and front of which are removed.

Fig. 81.

In order to use this photometer, place the two sources as shown in the diagram and adjust their distances till the blocks appear equally bright.

Exercises

(1) Compare the illuminating powers of two sources by using paraffin block photometer.

(2) Verify the law of inverse squares by using paraffin block photometer.

CHAPTER XX

LAWS OF REFLECTION OF LIGHT

Reflection of light.—When light falls on a surface, a part of it is reflected regularly, a part of it is scattered, a part of it is absorbed, and a part of it is refracted. The nature of the surface and the angle of incidence together determine the proportion of the various parts.

Laws of reflection of light :—

(*i*) The angle of incidence is equal to the angle of reflection.

(*ii*) The incident ray, the reflected ray and the normal at the point of incidence lie in the same plane *viz.,* the plane perpendicular to the reflecting surface.

Experiment 61.—(*a*) **To prove the laws of reflection of light.**

(*b*) **To prove that the image is as far behind the mirror as the object is in front of it.**

Apparatus.—A strip of mirror, a cork with a vertical slit to hold the mirror, a drawing board, pins, metre rod, protractor, set squre, drawing pins.

Method I.—Fix a sheet of paper to a drawing board with drawing pins. Fix the mirror in a piece of cork and place it vertically upon the sheet of paper. Trace out the boundary of the mirror. If it is appreciably thick, there will be a certain amount of refraction of light on entering and leaving the glass. In order to counteract this defect, draw a line ST at a distance of one third the thickness of glass from the back surface and treat this line as the actual reflecting surface. If the mirror

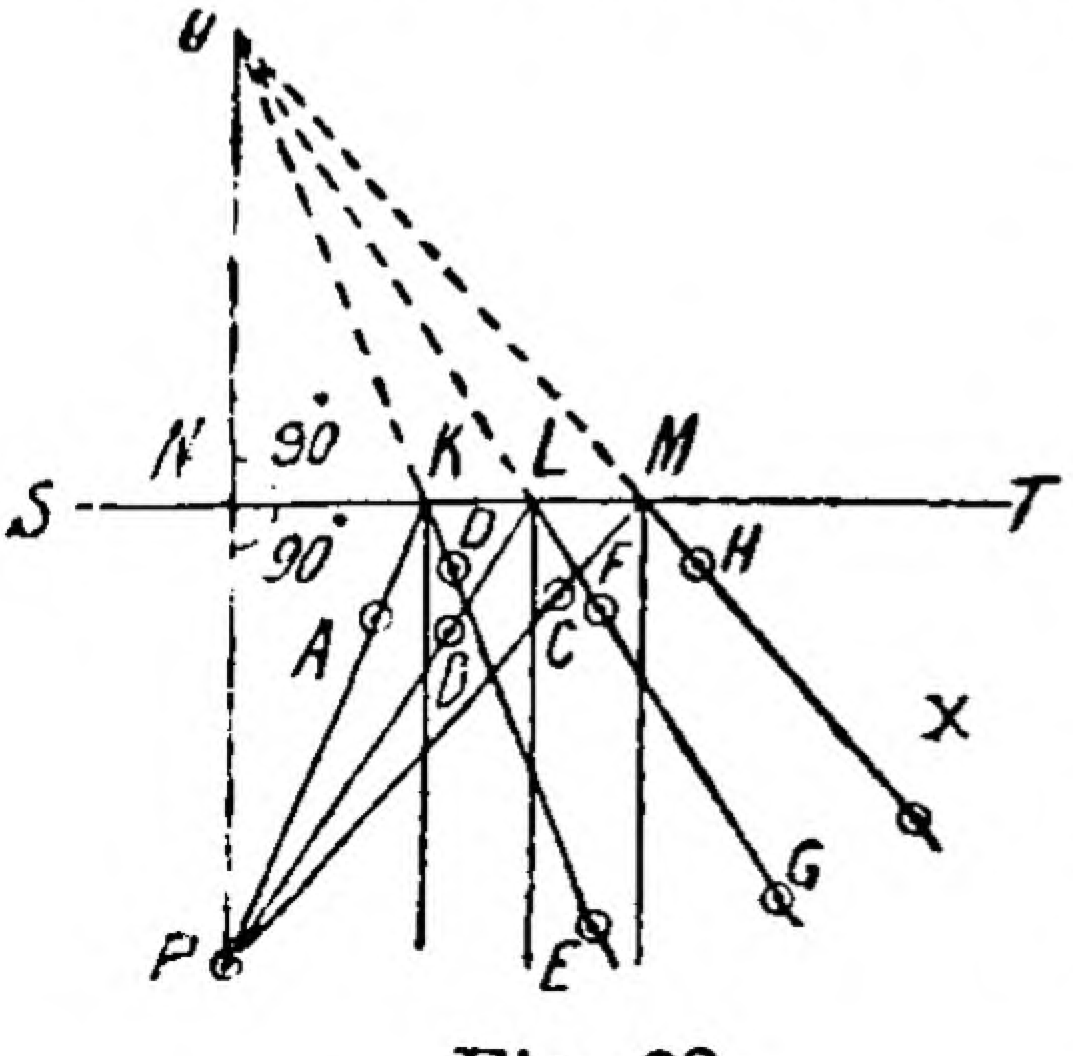


Fig. 82.

is thin, its back silvered surface may be placed on the line drawn on the paper. Take a point P in front of the line at some distance from it, and draw a number of lines from it to meet the line ST in the points K, L and M respectively. These lines represent the directions of the incident rays. Place the mirror back on the paper in a vertical position. Fix a pin at P and move another pin from one incident ray to the other. Trace the reflected ray corresponding to each incident ray by fixing pins at D and E in a line with the images of P and A, and at F and G in a line with the images of P and B, and at H and X in a line with the images of P and C. See that in no case the distance between two pins is less than 8 or 9 cms. After removing the mirror and the pins, mark the direction of the reflected rays, which will meet the line ST in the same points in which the incident rays are meeting. At the points K, L and M draw normals. Measure the angles of incidence and of reflection and tabulate them.

Produce the reflected rays backwards by dotted lines. The point Q where the reflected rays meet is the virtual image of the point P. Join the points P and Q by a straight line cutting ST in N. Measure the lengths of the lines NQ and NP and the angles PNT and QNT.

Record thus :—

No. of observations	Angle of incidence	Angle of reflection	Length of PN	Length of QN	∠PNT	∠QNT
1.						
2.						
3.						
4.						
5.						

Malhan...

Method II. Place a pin P in front of a plane vertical mirror. Looking along some direction SR, fix pins at R and S so that these are in a line with the image of P. Similarly looking along the direction S′R′ fix pins at R′ and S′ so that these are in a line with the image of P. Remove the pins and draw a small circle round each point from which a pin is taken. Join the points R and S as well as R′ and S′ by fine lines drawn with a well chisled pencil. Produce the lines backwards and le them intersect at the point Q. Then Q is the image of P.

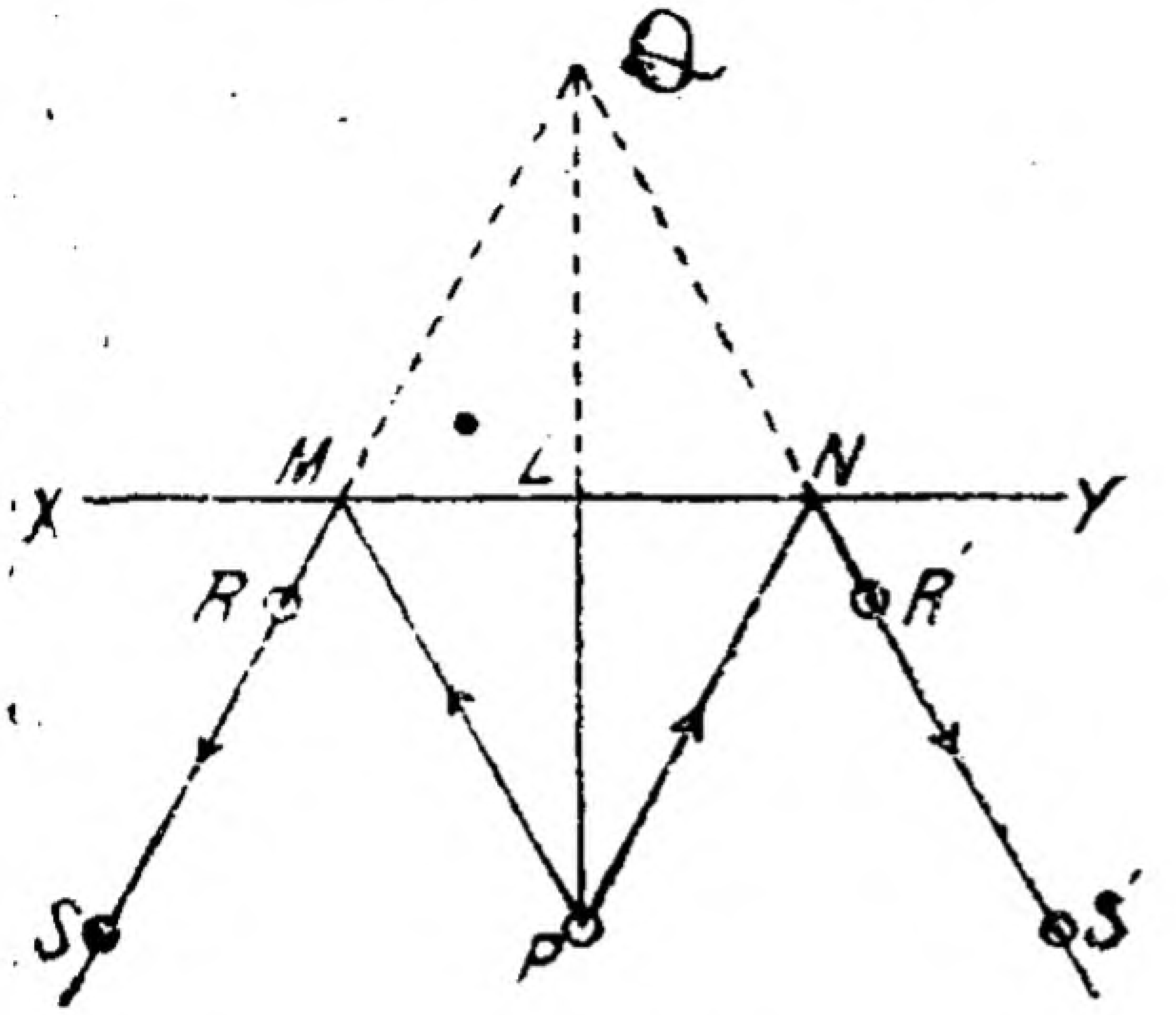


Fig. 83.

Join Q and P by a straight line cutting the line XY which is the actual reflecting surface in L. Measure QL and PL and the angles which QL and PL make with XY. It will be found that QL=PL and that the line QP is perpendicular to XY.

Join the point P to the points M and N respectively. At the points M and N draw normals and measure the angles of incidence and reflection.

Repeat your observations.

Record thus .—

No. of obs.	Angle of incidence	Angle of reflection	Distance of object PL	Distance of image QL	Angle PLX

Precautions : 1. The bases of the pins and not their heads should be in a straight line.

2. The distance between two pins should not be less than 8 cms.

3. The actual reflecting surface is at a distance of one-third the thickness of glass from the back face, when the mirror is thick.

4. Draw small circles round the pin-pricks before removing them and draw lines accurately through the pin-pricks with a well sharpened pencil.

5. The mirror should be placed vertically on the sheet of paper.

6. The rays should be sufficiently inclined to the mirror.

Sources of error. (1) The mirror may not be plane. The presence of more than one reflecting surface causes confusion.

(2) The illuminated bodies may not be having a sharp boundary.

Experiment 62. **To prove that when a mirror is turned through a certain angle, the reflected ray moves through twice that angle.**

Apparatus.—Same as in the previous experiment.

Method.—Fix a sheet of paper to a drawing board, and draw two lines AB and CD on it as shown in Fig. 84. Measure the angle θ between the two lines, which is the angle through which the mirror turns. Draw the line EK, and let it stand for the incident ray in the two positions of the mirror. Fix pins at E and F vertically on the line EK. Place the mirror on AB, and

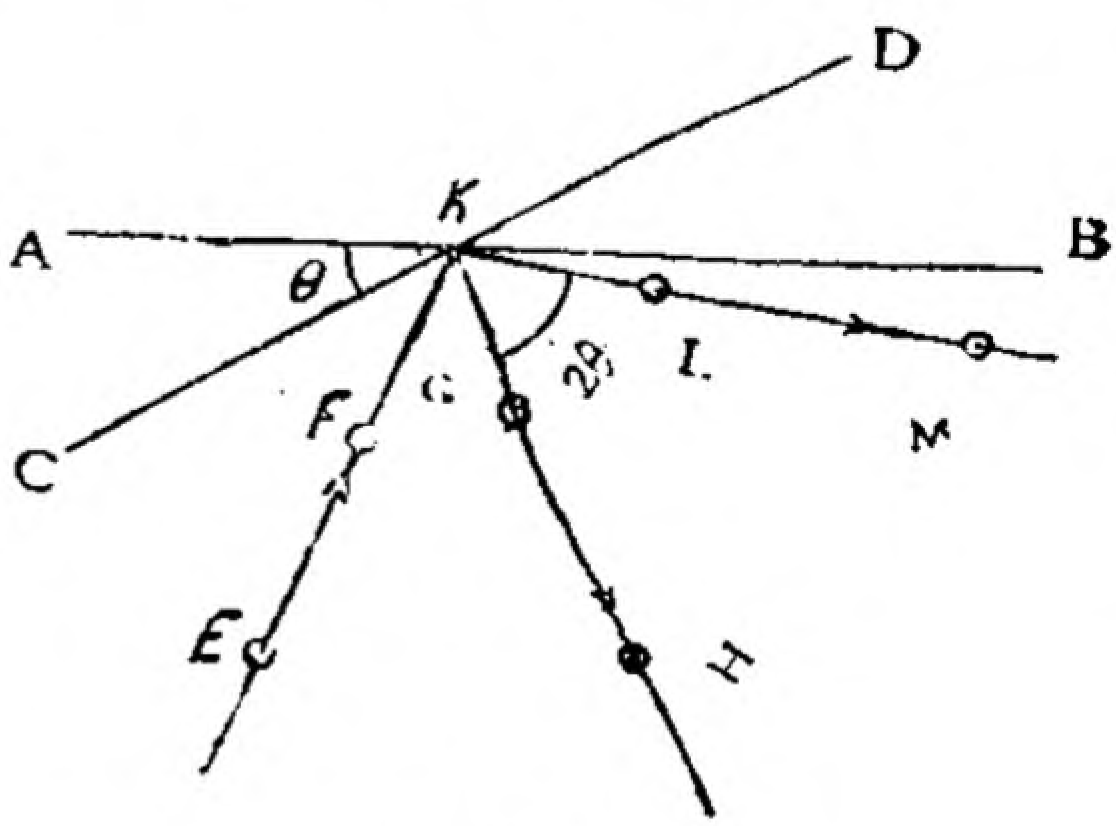


Fig. 84.

fix pins at G and H such that these are in a line with the images of E and F. Next place the mirror on CD, and by looking through it fix pins at L and M in a line with the

images of E and F. Remove the mirror, and draw a small circle round each point from which the pin is removed. Mark the direction of the reflected rays by joining the points H and G and M and L by straight lines, which on being produced will meet at the point K. Measure the angle HKM between the two reflected rays. It will be seen that the angle HKM is double of angle AKC.

Repeat your observations with different angles between the positions of the mirror.

Record thus :—

No. of observations.	Angle through which the mirror turns (θ)	Angle through which the reflected ray moves.	Correct value of 2θ	Error.
1.				
2.				
3.				

Precautions.—Same as in the previous experiment.

Parallax

Take a pencil in your hand and keep it in front of one of the bars of a window, so that the pencil hides the bar. Close one of your eyes, and move the other to the right and left. You will notice that there will be produced relative shift between the two objects. *The relative shift thus produced is known as parallax.* It will be noticed that the *far off object* will move in the direction of eye whereas *the near object* will move in a direction opposite to that of the eye. There is parallax between the two objects. But when the two objects lie in one plane and one above the other, no relative motion will occur as the eye is moved, *viz.*, parallax will disappear.

The following experiment is very instructive in illustrating the meaning of parallax.

Draw a thick black line on cardboard and divide it into two equal parts with a pair of sharp scissors. Pin the two cards to a drawing board which is clamped vertically, so that the two thick lines X and Y are in one straight line. Standing at some distance away from the two surfaces, you will notice that in this position of the two halves of the cardboard, there is no parallax.

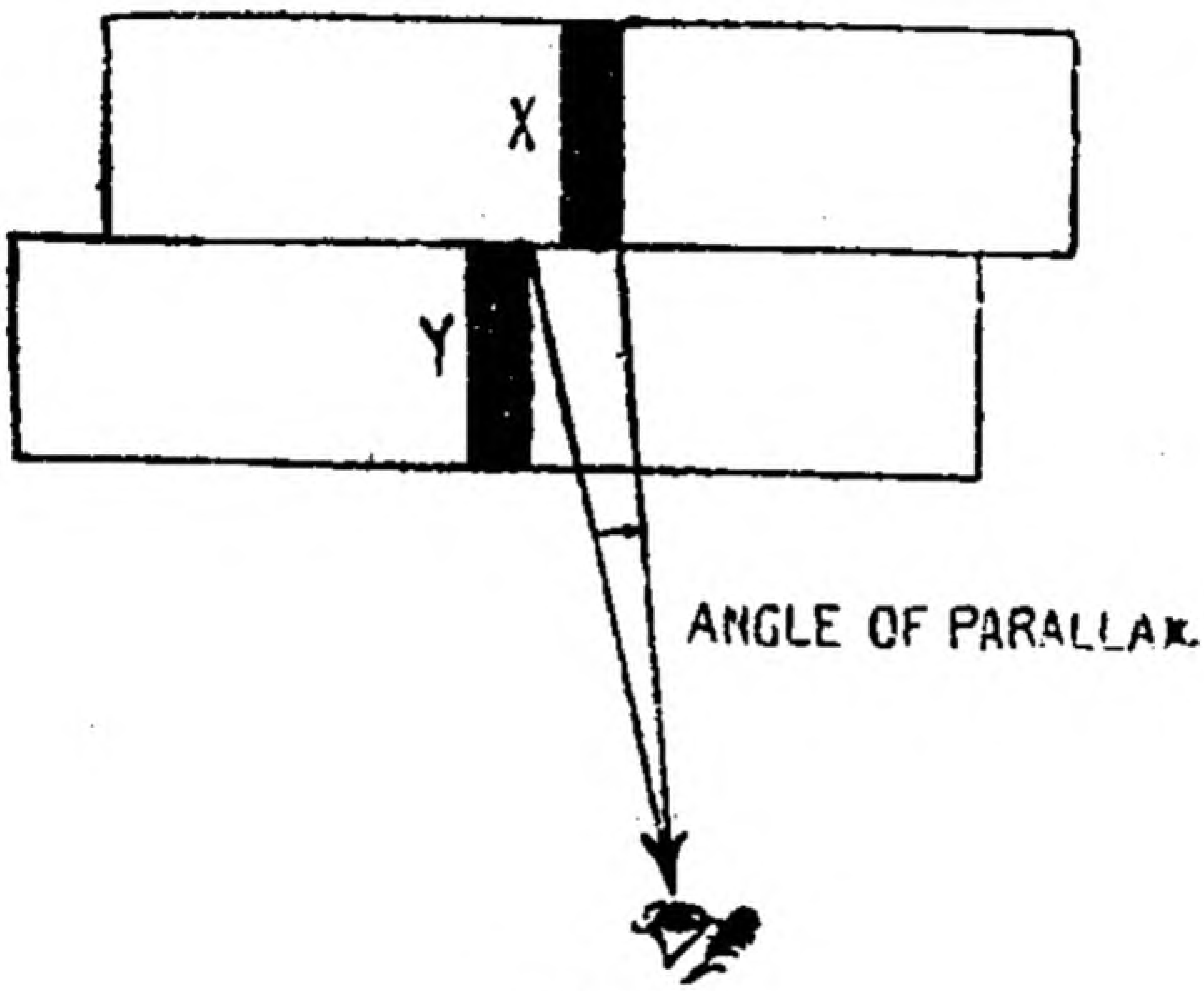


Fig. 85.

Now pin the two cards so that the upper piece, is a short distance in front of the lower piece, as is evident from the figure. In this position you will notice that there is parallax between the lines X and Y. The line X will move in the direction of the eye. The angle of displacement subtended at the eye of the observer is the **angle of parallax**.

Thus when the two objects are in one plane and one above the other, there is no parallax between them.

The method of parallax enables us to locate the position of image.

Experiment 63.—**To find the position of virtual image of an object formed by a plane mirror by the method of parallax.**

Apparatus.—Plane mirror, set square, a metre rod, drawing board, paper, pins, drawing pins, a hard drawing pencil.

Method I. Place the mirror on the paper which is pinned to the drawing board and let LM be the actually reflecting surface (marked as explained before). Fix a pin at A in front of the mirror. Take a tall pin B and fix it behind the mirror so that there is no parallax between the projecting part of the pin above the edge of the mirror and the reflected image of the pin at A. Let B represent the position of the search pin.

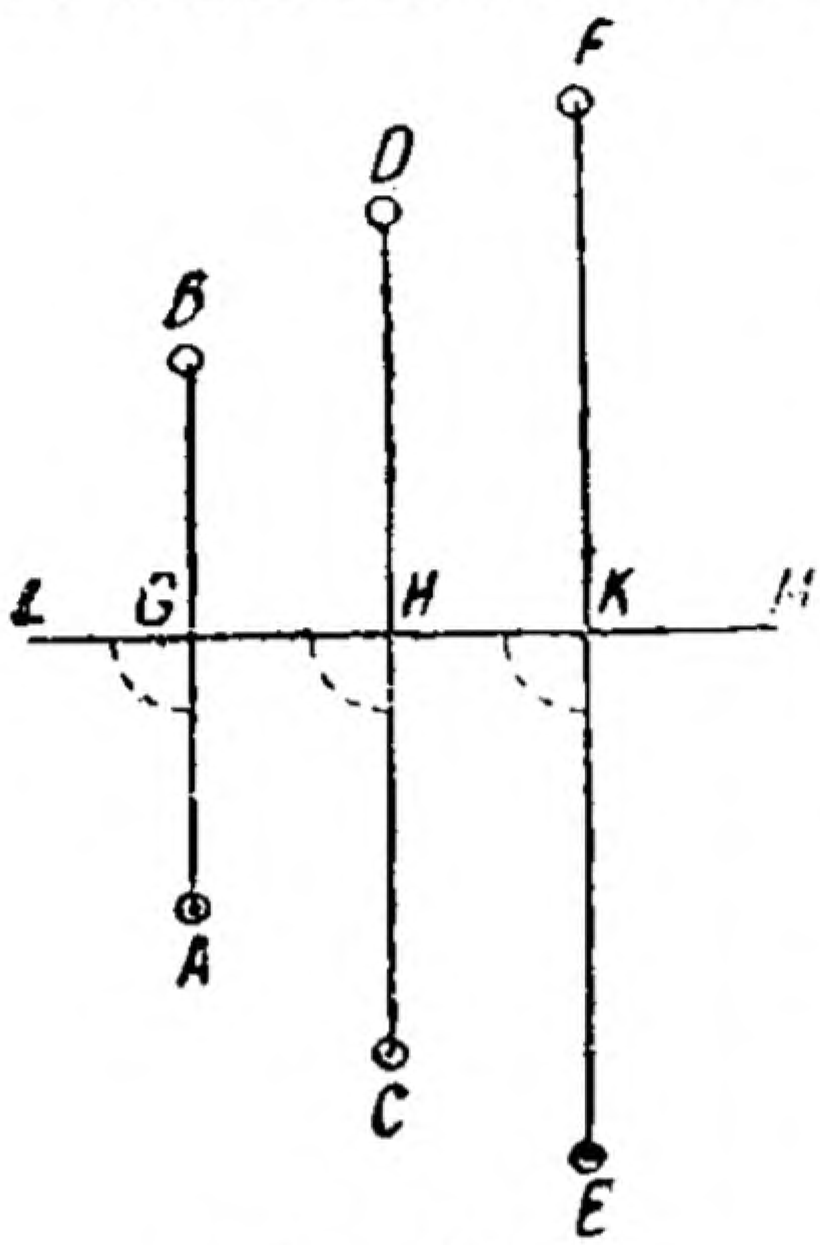


Fig. 86.

Locate in the same way the images of the pins at C and E. Remove the mirror and the pins after drawing small circles round the pin pricks. Join the point A to B, and the point C to D, and the point E to F. Measure the angles which these lines make with LM and the distance of the object and the image from LM in each case.

Record thus :—

No. of observations	Distance of object from LM	Distance of image from LM	Angle between the line joining image to object and the line LM
1.			
2.			
3.			
4.			

Method II.—The position of the image can be located in another way. Remove silver from the middle portion of the

mirror so that a slit is formed. Fix a pin at A in front of the mirror and move another pin B behind the mirror such that there is no parallax between the pin B as seen through the unsilvered portion of glass, and the image of A as seen in the silvered portion.

Exercises

(1) Place two strips of plane mirror vertically on a sheet of paper, with their reflecting surfaces inclined at 120°. Fix a pin vertically at any point between the mirror. Locate the images.

(2) An object remains fixed in front of a plane mirror while the mirror is displaced parallel to its first position through a distance of 3 cms. Prove that the image will move through a distance of 6 cms.

(3) Place two mirrors facing and parallel to one another, and about three inches apart. Insert a pin between the mirrors and about one inch from one of them. Find the position of the successive images by the method of parallax.

(4) Trace the path of a ray of light as reflected from a mirror corresponding to an angle of incidence equal to 30°. Measure the angle of deviation.

(5) Place two mirrors inclined at an angle of 60° to each other. Trace the path of a ray of light which suffers two reflections. Measure the angle of deviation.

(6) Place two mirrors inclined to each other at an angle of 90° and trace all the images that you see.

(7) Show that the deviation of a ray of light which suffers two successive reflections from two plane mirrors inclined at a certain angle is independent of the angle of incidence.

CHAPTER XXI

REFRACTION OF LIGHT

Refraction of light.—Light travels in a straight line in a homogeneous medium. But when a ray of light enters a second medium of different density, it is bent. The bent ray of light is called *refracted ray*, and the phenomenon is spoken of as *refraction of light.* If a normal be drawn at the point of incidence to the surface of separation between two media, the angle between the incident ray and normal is the *angle of incidence* and that between the refracted ray and normal is the *angle of refraction*.

Laws of refraction of light.

(I) The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant quantity for any two given media for light of a given colour.

If i and r were to denote respectively the angles of incidence and refraction, then

$\frac{\sin i}{\sin r}=\mu$ (constant). This constant is known as *index of refraction* or *refractive index* of the second medium with respect to the first.

(II) The incident ray, the refracted ray and normal to the surface at the point of incidence lie in one plane.

Table of Refractive Indices.

Glass	1·52
Water	1·33
Carbon Bisulphide	1·63
Diamond	2·42

Experiment 64.—**To verify the laws of refraction and to determine the index of refraction (μ) of glass.**

Apparatus.—Glass block, metre rod, a pair of compasses, pins, paper, drawing board.

Method.—Place a rectangular block of glass on the paper and trace out its boundary with a well pointed drawing pencil. Select a point A in one of the longer sides and draw a normal through it. Draw the lines BA, CA, and DA

converging to A. Put the block back in the previous position and fix pins at B and K on the line BA. Looking through the opposite face of the block, stick pins at P_1 and Q_1 so that the four pins appear in a line. In the same way, fix pins at P_2 and Q_2 so that these appear to be in line with the images of the pins at C and L on the line CA, and P_3 and Q_3 appear in a line with the images of the pins at D and M on the line DA.

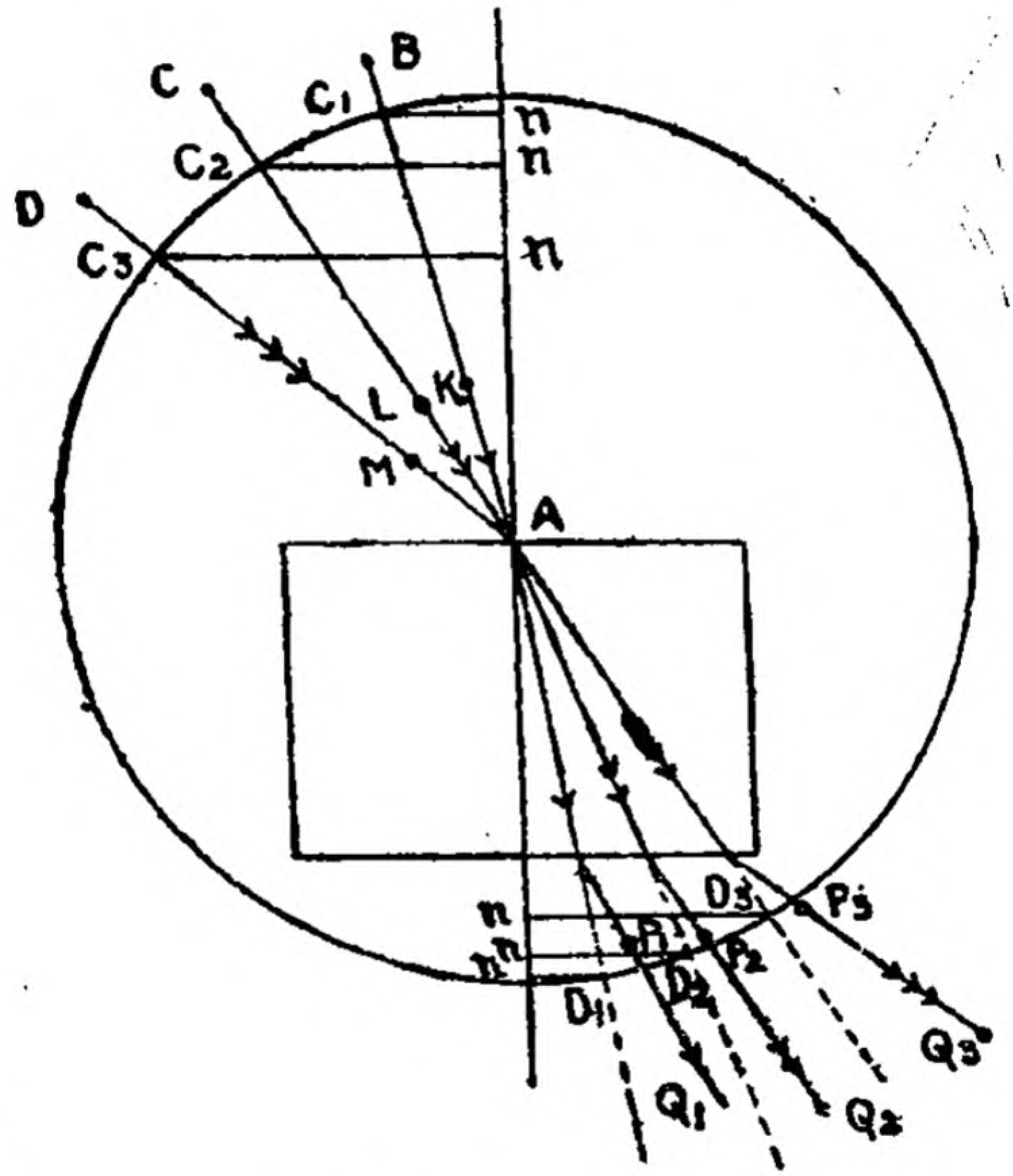


Fig. 87.

Remove the block and draw lines joining P_1Q_1, P_2Q_2, and P_3Q_3 and produce them to meet the near edge of the block. Join the points so obtained to the point A so as to get the path of refracted rays.

With A as centre draw as large a circle as possible and from the points of intersection of the circle with the incident and refracted rays (produced if necessary) draw perpendiculars to the normal through A.

In the case of ray BKP_1Q_1

$$\mu=\frac{\text{Sin } i}{\text{Sin } r}=\frac{\text{Sin BA}n}{\text{Sin D}_1\text{A}n}=\frac{C_1n}{C_1A}\div\frac{D_1n}{D_1A}$$

$$=\frac{C_1n}{D_1n},\text{ since } C_1A=D_1A$$

being the radii of the same circle.

Measure the lengths C_1n, C_2n, C_3n, D_1n, D_2n and D_3n and calculate the ratios $\frac{C_1n}{D_1n}$, $\frac{C_2n}{D_2n}$, $\frac{C_3n}{D_3n}$. The ratios so obtained will be found to be equal and the value so obtained will be the refractive index of glass.

Let d stand for the lengths of the perpendiculars C_1n, C_2n, C_3n and d_1 for the lengths of the perpendiculars D_1n, D_2n, D_3n.

Measure the angles of incidence and refraction with a protractor, and find out their sines from the tables. Determine the ratio $\frac{\sin i}{\sin r}$ for each ray. They will be the same and equal to $\frac{d}{d_1}$.

Record thus :—

No. of observations.	i	r	Sin i	Sin r	$\mu=\frac{Sin\ i}{Sin\ r}$	d	d_1	$\frac{d}{d_1}=\mu$	Mean μ
1.									
2.									
3.									
4.									
5.									

Since the ratio of the sine of the angle of incidence to the sine of the angle of refraction remains constant, so the first law is verified.

Moreover the incident rays, the refracted rays and the normal, all lie on the same paper, so they lie in the same plane.

Draw a graph between Sin i and Sin r and find the refractive index of the given substance from the graph [The graph in this case is a straight line passing through the origin. In the equation $\mu = Sin\ i/Sin\ r$, let $sin\ i$ be equal to y, $sin\ r$ equal to x and μ equal to m, then $y/x = m$ or $y = mx$, which is the equation of the straight line passing through the origin.]

Precautions :—1. Same as in other pin experiments.

2. Very small or very large angles should be avoided.

Experiment 65.—**To prove that for a given angle of incidence the displacement of a ray after passing through a rectangular glass slab is proportional to thickness.**

Apparatus.—Rectangular glass slab, pins, paper, drawing board, metre rod, set square, protractor.

Method.—Place the rectangular glass slab on the paper which is pinned to the drawing board, and trace its boundary with a sharp pencil. At any point N draw the normal MN and with the normal make the angle PNM equal to the given angle (say 30°). On the incident ray PN fix pins at P and Q. Looking through the opposite face of the slab, fix pins at R and S such that these are in a line with the images of P and Q.

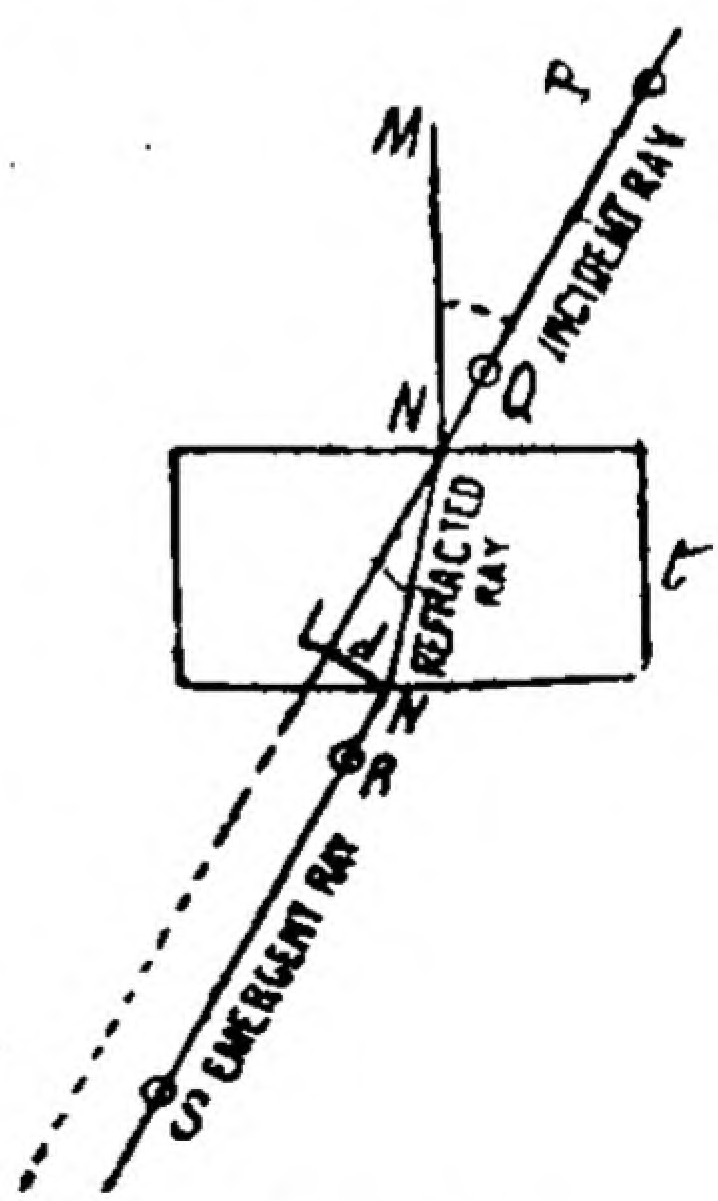


Fig. 88.

After drawing small circles round the pin holes remove the pins and draw lines accurately through the pin holes. Join the points N and N' where the incident and the emergent rays meet the two surfaces respectively.

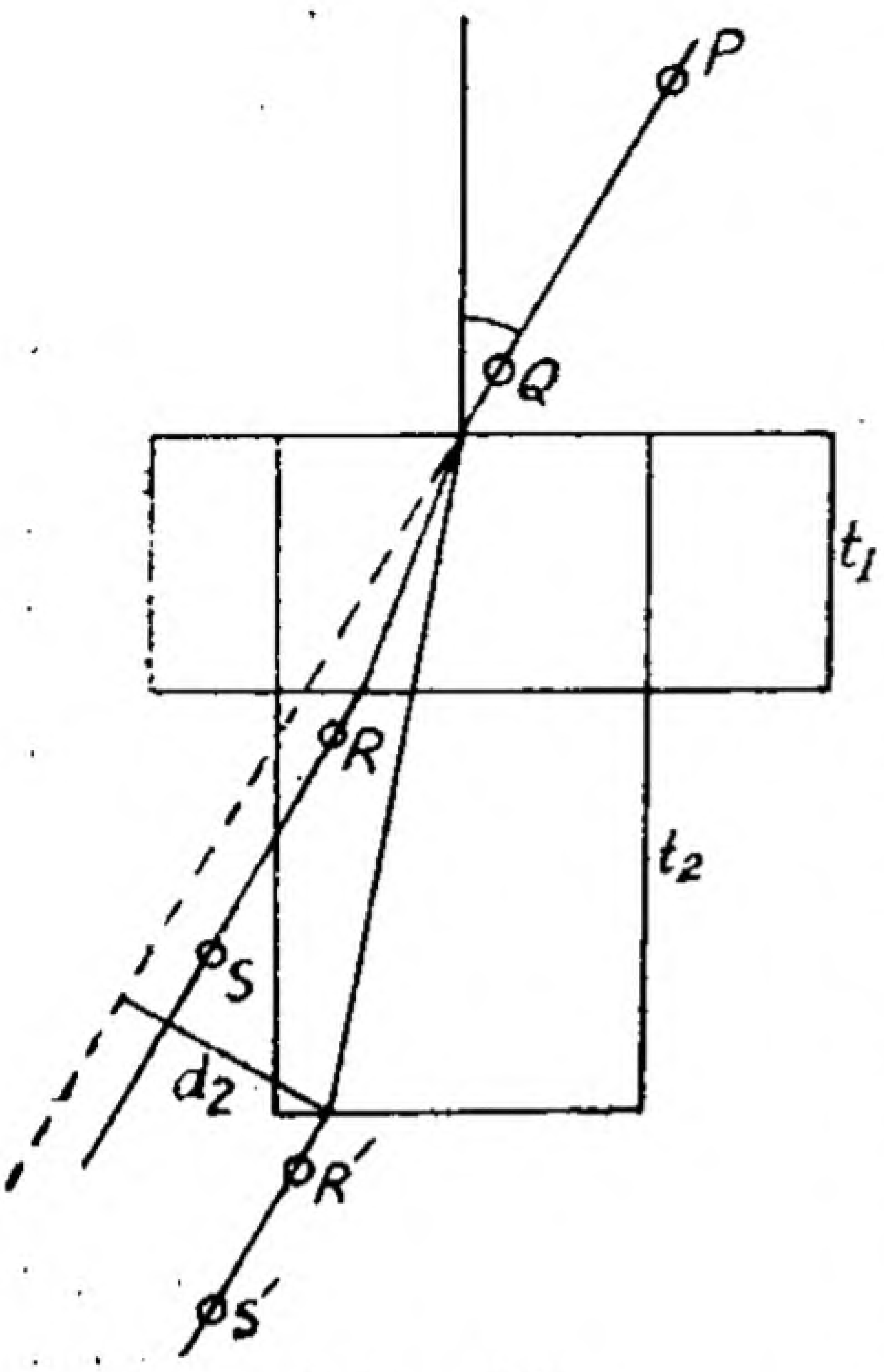


Fig. 89.

The line NN′ is the refracted ray. Produce the incident ray downward by dotted line. The incident ray and the emergent ray will be found to be parallel to each other. Measure the perpendicular distance d between the two rays, and the thickness t of the glass slab. Find the ratio of the two. Keeping the angle of incidence constant, use the other two thicknesses t_1 and t_2 respectively, and find the displacements d_1 and d_2. Find the ratios d_1/t_1 and d_2/t_2. The ratio displacement to thickness in all the three cases will be found to be constant. The line d_1 is not shown in the figure, but it is the perpendicular distance between the dotted line and RS.

Record thus :—

Angle of incidence	Thickness	Displacement	$\frac{\text{Displacement}}{\text{Thickness}}$
	t cms.	d cms.	$\frac{d}{t}$
	t_1 cms.	d_1 cms.	$\frac{d_1}{t_1}$
	t_2 cms.	d_2 cms.	$\frac{d_2}{t_2}$

Try the experiment with some other angle of incidence and prove that displacement is proportional to thickness.

Exercises

(1) Find the refractive index of water by tracing the course of rays with pins through a hollow cubical vessel containing the given liquid.

(2) With the help of *semicircular glass slab* determine the refractive index of glass. Draw a graph showing the relation between sin i and sin r.

[*Hints*.—After drawing a circle, draw two diameters at right angles to one another. Place the semicircular disc with its centre coinciding with the point P. Let PA be an incident ray with pins at P and A respectively. Looking through the curved side of the disc fix a pin at Q in a line with the images of P and A. In this case the refracted and emergent rays both coincide. One pin at Q is sufficient to mark the position of the refracted ray. Join P to Q so as to get the position of the refracted ray, and produce it to meet the circumference of the circle. Measure the angles of incidence and refraction. Find the refracted rays corresponding to a number of other incident rays. Find the sines of the angles of incidence and refraction and calculate the refractive index of the material of the slab.

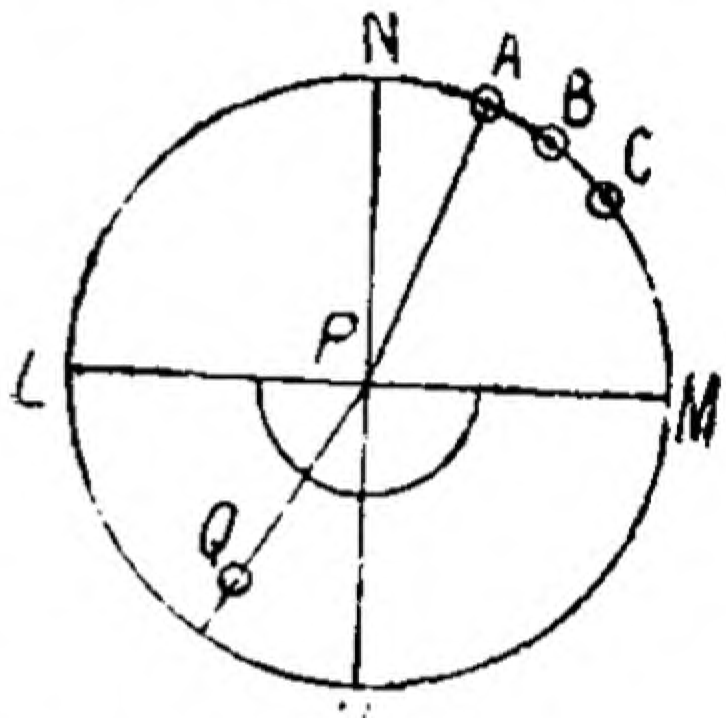


Fig. 90.

Plot a graph between sin i and sin r.

(3) Show that for a given thickness, the displacement is proportional to the sine of the angle of incidence when a ray of light passes through a rectangular glass slab.

Experiment 66.—**To determine the refractive index of** (*i*) **glass and** (*ii*) **water, by measuring its apparent depth.**

Apparatus.—A rectangular glass slab, a beaker containing water, a piece of black paper, a needle, a metre—stick, two knitting needles, a drawing board, a sheet of paper and a retort stand with a clamp.

Method.—(1) **Glass.**—Fix a paper on a drawing board and draw a line on it. Place the glass slab with the tall end up over the line. Clamp a needle horizontally in a stand, and on looking from above remove parallax between the

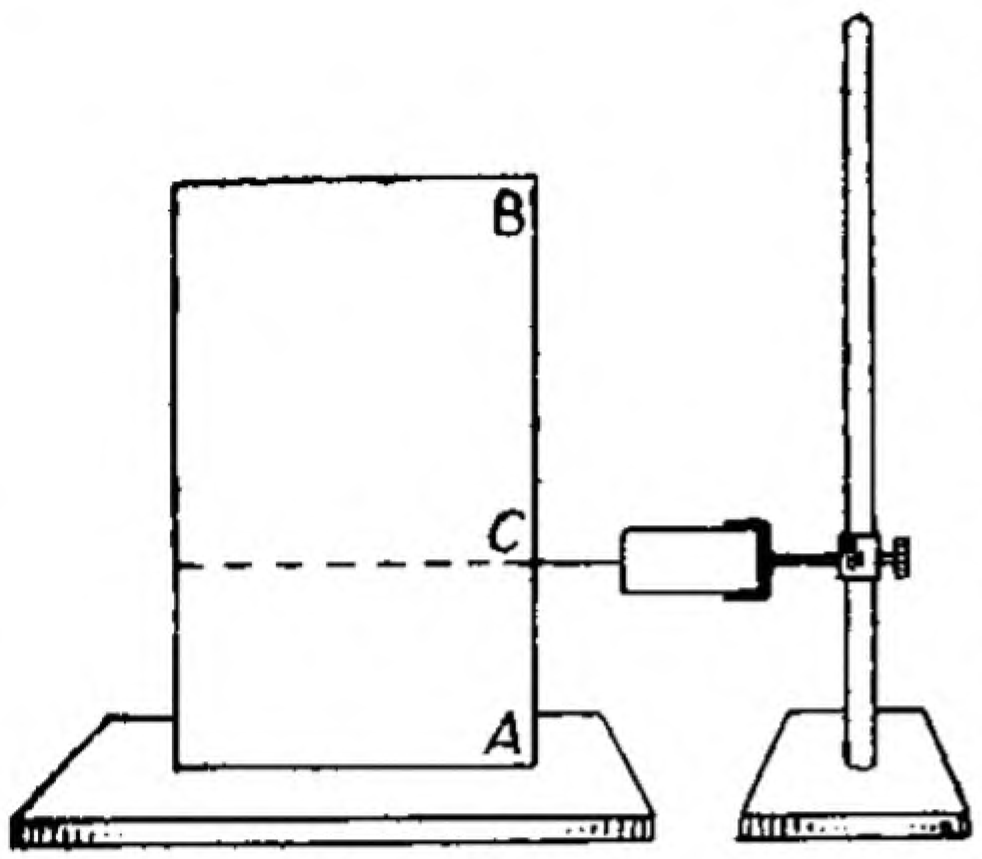


Fig. 91.

image of the line and the needle. This will be the case when the needle has been adjusted where the image of the line is formed. With the help of two knitting needles find the distance between the top of glass slab and the needle, and then measure the distance between the tips of the knitting needles on a metre stick. This will give the apparent thickness of glass slab. Find the **real thickness** of glass slab. Apparent thickness is deduced indirectly by subtracting from the real thickness AB, the distance AC through which the object appears to have risen. Refractive index of glass is equal to the ratio, real depth/apparent depth. By putting different edges of the slab on the line, repeat the experiment.

Record your observations thus :—

No. of obs.	Real thickness or depth	Apparent rise of object	Apparent thickness or depth	$\mu = \dfrac{\text{Real thickness or depth}}{\text{Apparent thickness or depth}}$

(2) **Water.**—Take a beaker or a tall jar containing water and drop a pin in it which will serve as an object. Take a needle and clamp it horizontally in a stand and by moving it up and down remove parallax between it and the image of the pin as seen from above through water. Measure the real depth, and the apparent depth. Calculate the ratio, real depth/apparent depth. This will be the refractive index of water.

Record your observations in a tabular form as shown above.

Precautions :—1. Keep the adjustable needle horizontal.

2. Use a thick layer of water, and the taller side of the glass slab

3. View the image of the line or pin normally.

Sources of error :—The method of measuring thickness or depth is not quite accurate.

Experiment 67.—**To determine the refractive index of water by removing parallax between the reflected image of the needle and the refracted image of the object.**

Apparatus.—Beaker, clamp stand, a needle, black paper, knitting needles, a pin and a metre scale.

Method.—Take a beaker containing water and place it on a black paper lying on a table. Drop a pin in it to serve as an object. Clamp a needle horizontally and place it above the surface of water. Look into water from above and you will see two images of the needle—a distinct image formed on account of reflection and a faint image due to refraction from the glass bottom of beaker. Concentrate upon the first image which is distinct and ignore the other one. By moving the needle up and down remove parallax between its reflected image and the refracted image of the pin in water. Measure the distance AB with the help of two knitting needles. It will give the apparent distance. By the laws of reflection of light the distance

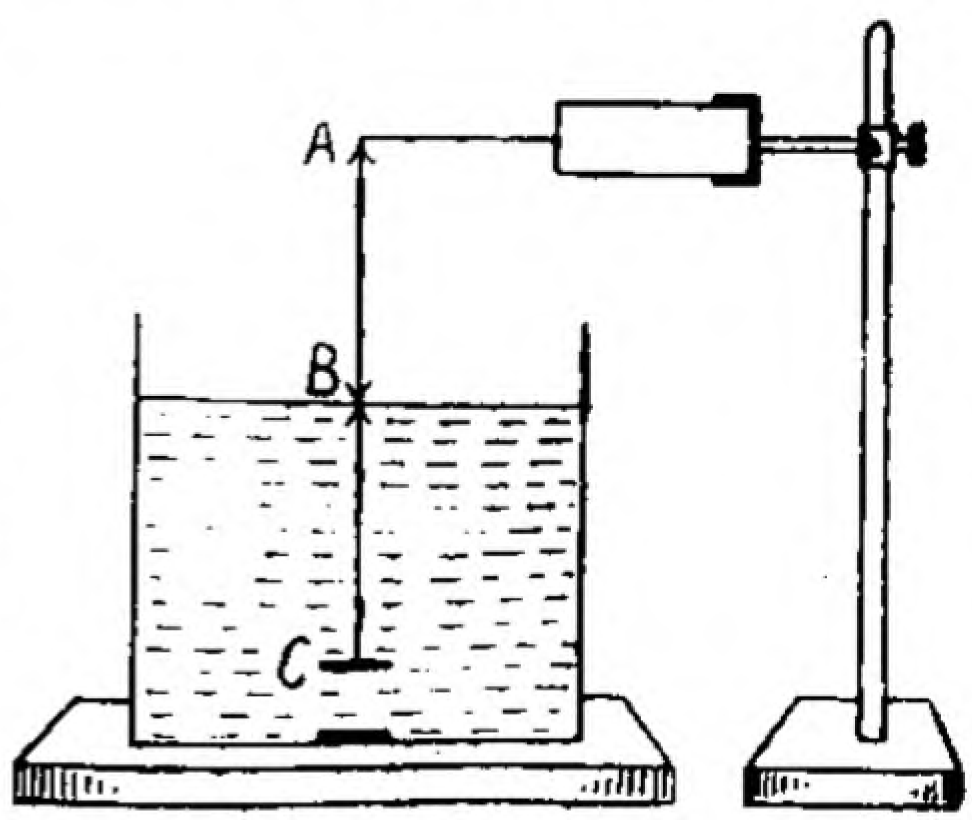


Fig. 92.

AB is equal to the distance BC. Measure the actual depth of water. The refractive index of water will be equal to the actual depth of water divided by the apparent depth.

Record your observations as follows :—

No. of Obs.	Actual depth of water (t)	Apparent depth of water (d)	$\mu = \frac{t}{d}$

Mean value of μ for water=......

Precautions :—Same as in the last experiment.

CHAPTER XXII

REFRACTION THROUGH A PRISM

A prism is a portion of a refracting medium bounded by at least two plane surfaces. The line along which the surfaces meet is the **edge** of the prism and the angle between them is the **angle** of the prism.

Relations in the case of a prism :—

(1) *Angle of incidence + Angle of emergence = Angle of deviation + Angle of prism,*

Proof :—Let KEFG represent the path of a ray of light through the prism. KE is the incident ray, EF the refracted ray and FG the emergent ray.

Let A = angle of prism, i_1 = angle of incidence, D = angle of deviation, and i_2 = angle of emergence, r_1 = angle of refraction at the first surface and r_2 = angle of incidence at the second surface.

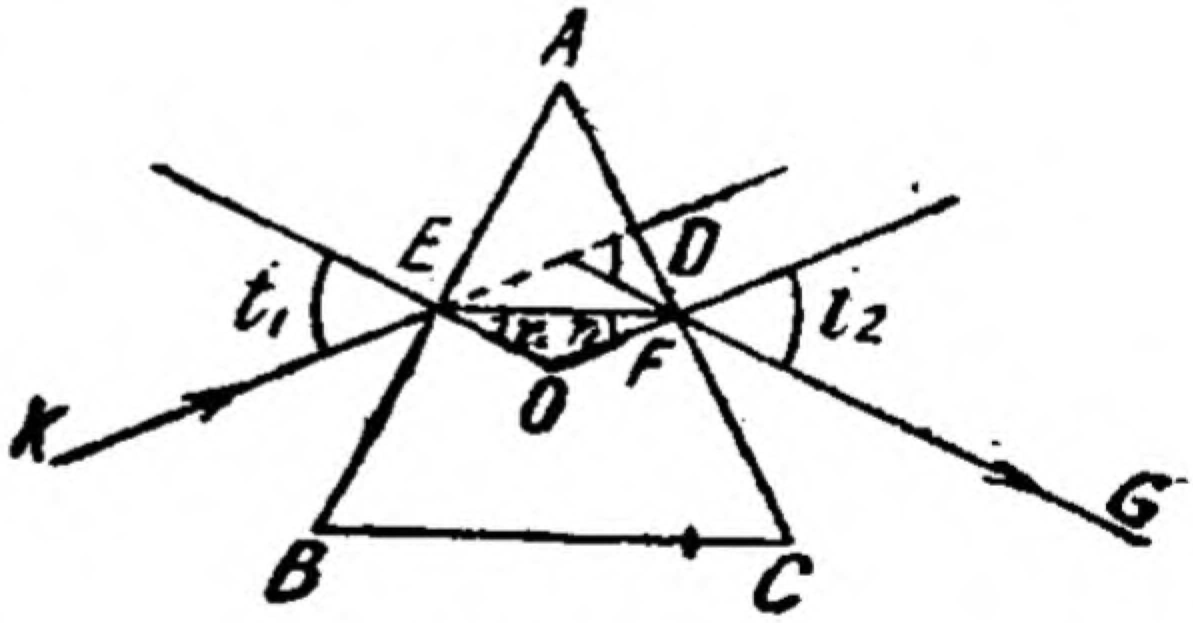


Fig. 93.

$D=(i_1-r_1)+(i_2-r_2)=(i_1+i_2)-(r_1+r_2)$ ...(*i*)

$\because$ the figure AEOF is a cyclic quadrilateral

$\therefore\ \angle A+\angle O=2$ rt. $\angle$s.

$\because\ \angle r_1+\angle r_2+\angle O=2$ rt. $\angle$s. [being angles of the triangle,]

$\therefore\ \angle A+\angle O=\angle r_1+\angle r_2+\angle O$

or $\angle A=\angle r_1+\angle r_2.$ ...(*ii*)

Substitute the value of (r_1+r_2) in (*i*)

$\therefore\qquad D=i_1+i_2-A$

or $\qquad D+A=i_1+i_2.$

(2) *If D be the angle of minimum deviation, then*

$$\mu = \frac{\sin \frac{1}{2}(A+D)}{\sin \frac{1}{2} A}.$$

Proof :—In the position of minimum deviation

$$r_1 = r_2 \text{ and } i_1 = i_2.$$

Let $\quad r_1 = r_2 = r$ and $i_1 = i_2 = i$

$$i_1 + i_2 = A + D \text{ [Proved]}$$

$\therefore \quad 2i = A + D$ or $i = \frac{A+D}{2}$

$$r_1 + r_2 = A \text{ [Proved]} \quad \therefore\ 2r = A \text{ or } r = \frac{A}{2}$$

$$\mu = \frac{\sin i}{\sin r} = \sin\frac{A+D}{2} / \sin\frac{A}{2}.$$

Experiment 68.—**To trace the course of rays through a prism and** (*i*) **to prove the relation $i_1 + i_2 = A + D$ and** (*ii*) **to plot a graph between angles of incidence and angles of deviation, and to find the angle of minimum deviation from the curve and to calculate the refractive index for glass.**

Apparatus.—Prism, pins, drawing board, paper, drawing pins, metre scale, protractor, set squares.

Method.—Take a sheet of paper and pin it to the drawing board. Draw a number of lines P_1, P_2, P_3, P_4, P_5, P_6, so that the angle between any two rays is 5°. Place a prism and adjust its position so that the extreme pins can be seen when looked at through the face AC. Trace the boundary of the prism with a pointed pencil. Fix a pin at P and another at 1 and looking through the face AC of the prism, stick pins at 1, 1 so that these appear to be in a line with the images of P1. Remove all the pins excepting P after marking the pin pricks and lettering them properly. Now fix a pin at 2 and trace the refracted ray, by a pair of pins 2, 2 corresponding to the incident ray P 2. Again remove all the pins excepting P after marking their positions accurately and labelling them. Proceed in the same way with the other rays. Complete the diagram.

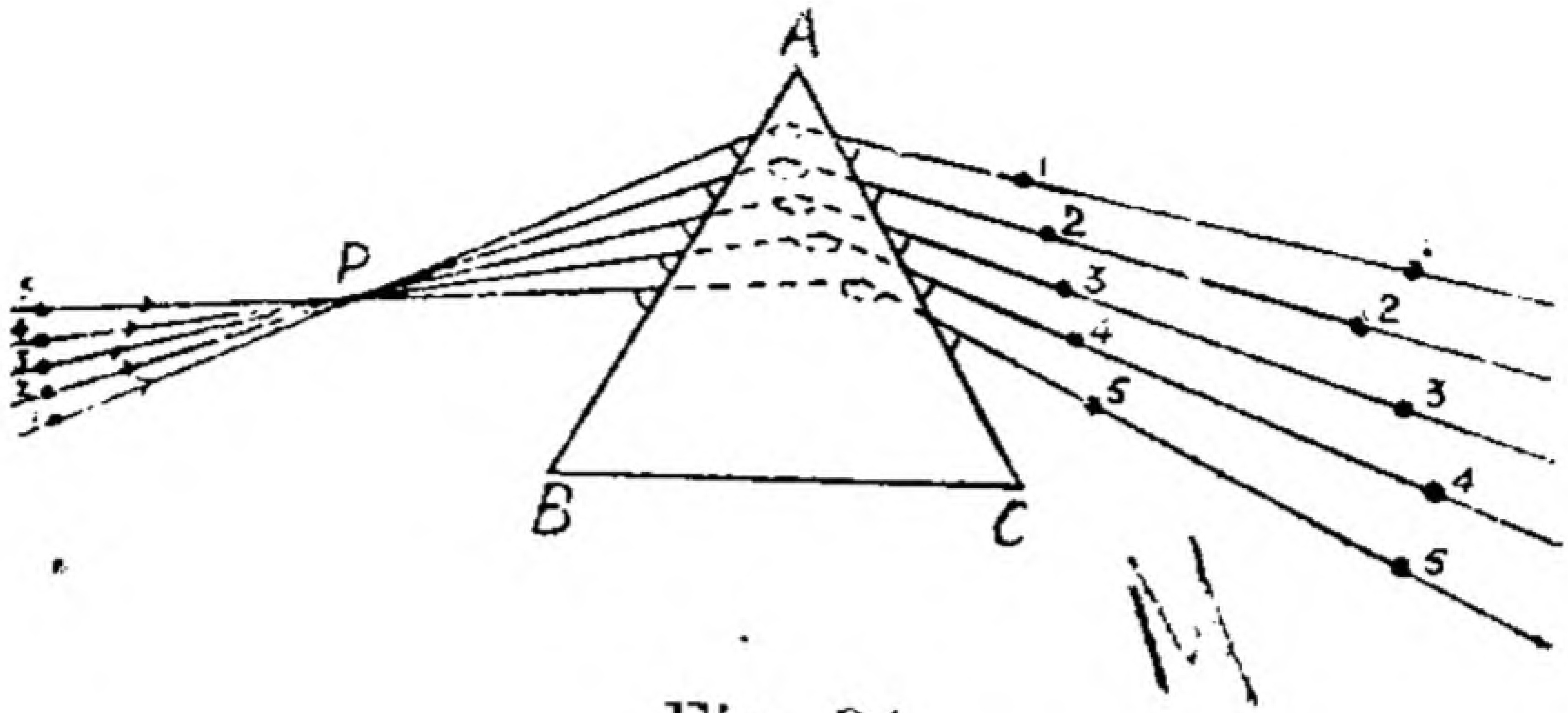


Fig. 94.

Measure the angles between the incident rays and the face **AB,** and between the emergent rays and the face **AC** of the prism. Subtract each angle from 90° and thus obtain the angles of incidence and emergence respectively. Measure the obtuse angles between the incident and emergent **rays.** The supplements of these will give the angles of **deviation.** Measure the angle A of prism.

Tabulate the angles as shown below :—

No. of obs.	Angles of incidence i_1	Angles of emergence i_2	Angles of deviation D	i_1+i_2	D+A

Plot a graph between the angles of incidence and angles of deviation Mark the lowest point on the curve and find the co-ordinates of this point. The angle of deviation thus found is the angle of minimum deviation.

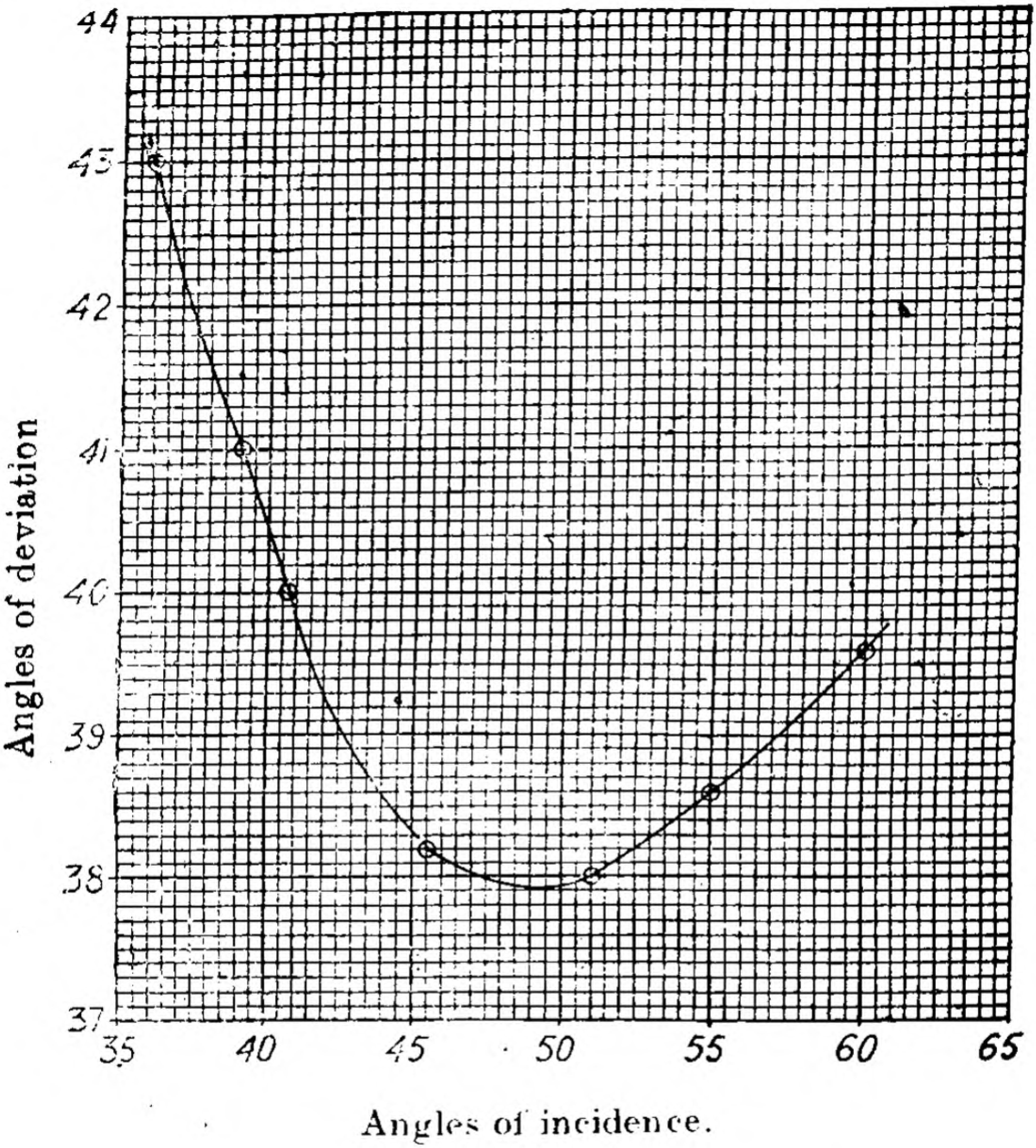


Fig. 95.

Calculate the refractive index of the material of the prism by substituting the values of D and A in the formula

$$\mu = \frac{\sin \frac{1}{2}(A+D)}{\sin \frac{1}{2}A}.$$

where D is the angle of minimum deviation, and A the angle of prism.

Note.—(1) A good graph for a 60^0 prism is obtained when the angles of incidence are of 35^0, 40^0, 45^0, 50^0, 55^0, and 60^0 respectively.

(2) As the incident rays are crowded on the face AB, so it will be a great help if a line is drawn parallel to AB and the corresponding angles are measured instead of the angles themselves.

Experiment 69.—**To determine the angle of minimum deviation and to find the refractive index of the material of the given prism.**

Apparatus.—Prism, pins, drawing board, drawing pins, paper, card-board, scissors, metre scale, protractor, set-squares.

Method.—Cut a piece of card-board having a pointed end, so that it will serve as a table for the prism to rotate. Fix a drawing pin in the revolving table and fix the prism on it with beeswax. Fix two pins vertically at P and Q and let the pin P be well illuminated. Looking through AC you will see a *coloured* image of the pin P. Now begin to rotate the prism table and watch the movement of the coloured pin. If it moves toward the base, the deviation is decreasing and if it moves away from the base the deviation is increasing. Continue to rotate the prism causing the coloured image of the pin P to move towards the base. While

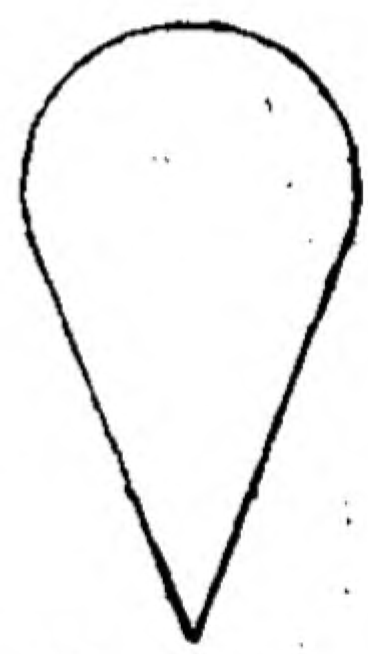


Fig. 96.

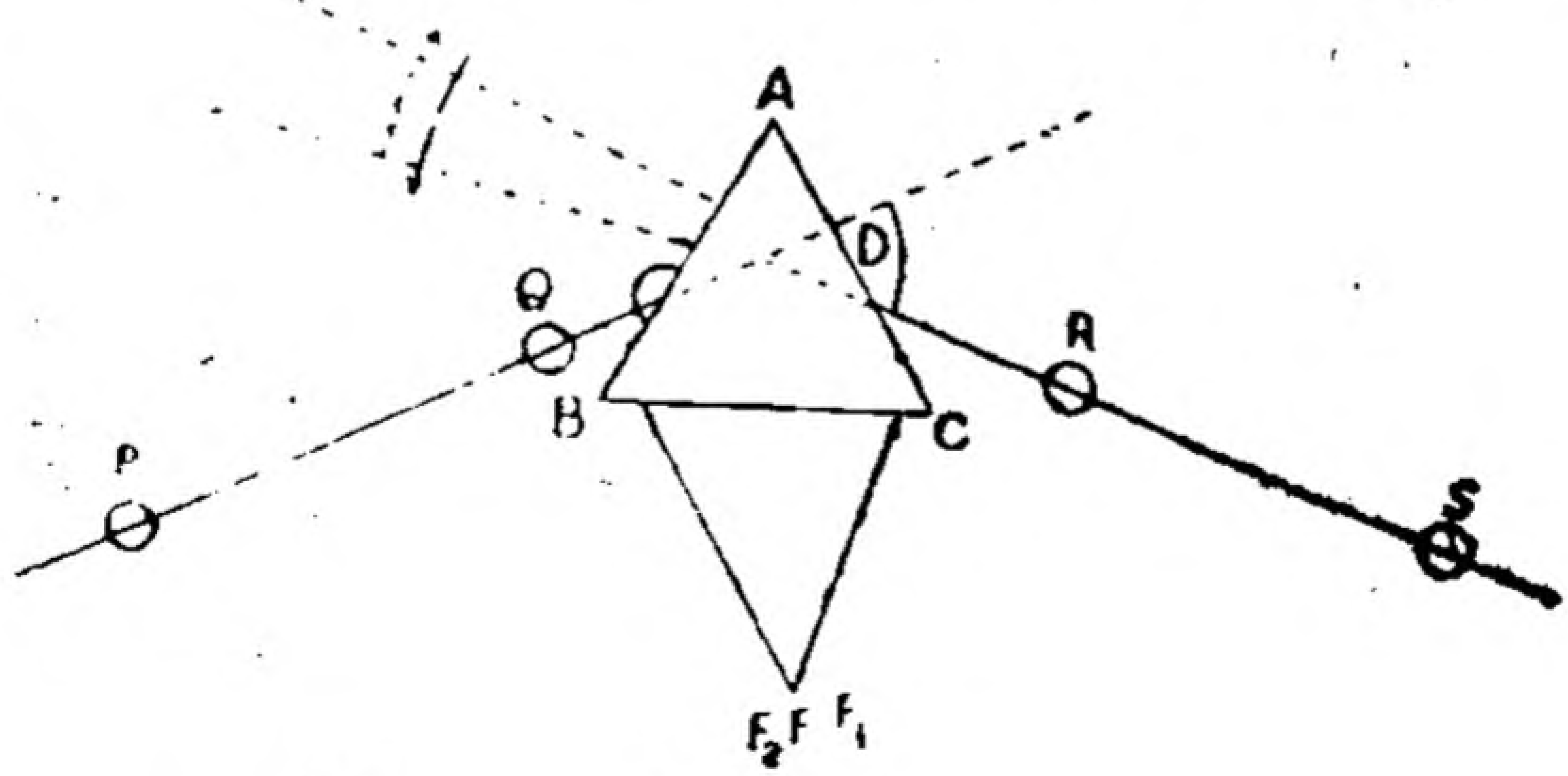


Fig. 97.

rotating the prism in this direction, a position will be reached when the coloured image will become stationary; and on rotating it a little more the pin will begin to turn back. Just when this happens, mark the position of the pointed end of the card-board, say at F_1. In the diagram the dotted line shows the direction in which the image of

P and Q appear as seen through AC and the full arrow the direction in which the dotted line moves, when deviation decreases. the dotted arrow shows when the dotted line begins to go back. Now turn the card-borad table a little further and then in the opposite direction. The coloured image of the pin will begin to move towards the base and will then become stationary. Rotating the prism-table little more, the image will begin to move back again. Mark the position of the pointed end of the card-board at F_2. Now divide the distance between F_1 and F_2 into equal halves and let F be the point of division. Place the pointed end of the card-board at F and mark the direotion of the emergent ray by fixing pins at R and S in a line with P and Q. With the help of a set-square mark the position of the prism by marking the points A, B and C. Remove the prism, the prism-table and the pins after drawing small circles round the pin-pricks. Draw the necessary lines and by producing the incident and emergent rays, measure the angle of minimum deviation. Repeat this experiment three or four times, drawing a separate diagram each time. Measure the angle of the prism from its outline by using a protractor. With the help of the formula $\mu = \frac{\sin \frac{1}{2}(A+D)}{\sin \frac{1}{2}A}$, calculate the refractive index of the material of the prism.

Record thus :—

angles of incidence	angles of emergence	Angle of minimum deviation	Angle of prism	Refractive index

Precautions.—1. The corners of the prism should be outside the revolving cardboard table.

2. Try to observe the motion of distant pin, and mark the position when the image first begins to turn back.

3. Use the same angle of the prism for different observations.

4. See that the prism is well fixed to the cardboard piece and that rotation takes place about the axis of the pin.

Total Internal Reflection.—AB is the surface of separation between two media of which the lower one is denser as compared to the upper one (Fig. 98). Let us suppose that light is coming from an object which is in the denser medium. There is a particular angle of incidence as shown in the figure, corresponding to which the refracted ray grazes along the surface AB. This particular angle of incidence (C) is called **critical angle. By determining the critical** angle, we can determine the refractive index of the medium from the relation $\sin C = \frac{1}{\mu}$. When a ray of light strikes the surface at an angle greater than the critical angle, it is reflected back in the same medium according to the laws of reflection of light. This phenomenon is spoken of as **total Internal reflection**, as the whole of the light is reflected and none of it suffers refraction.

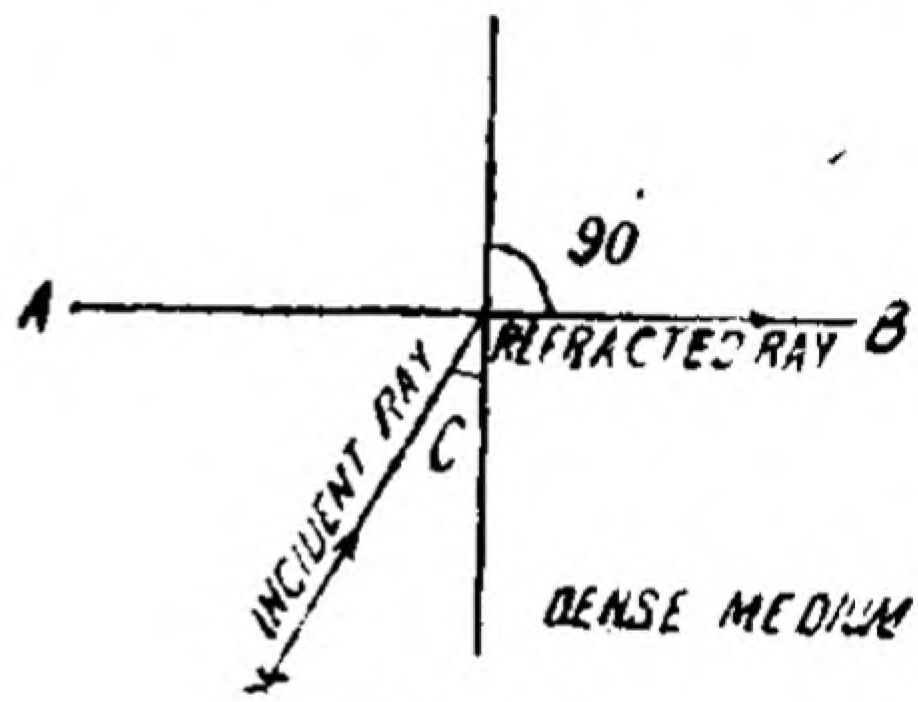


Fig. 98.

Experiment 70.—**To trace the path of a ray of light totally reflected in a Prism.**

Apparatus.—Drawing board, paper, pins, prism, set squares, metre-stick, protractor.

Method.—Place the prism so that its apex is towards you, and the base away from you, and mark its boundary on the paper. Place pins at P and Q so that PQ is nearly normal to the face AB.

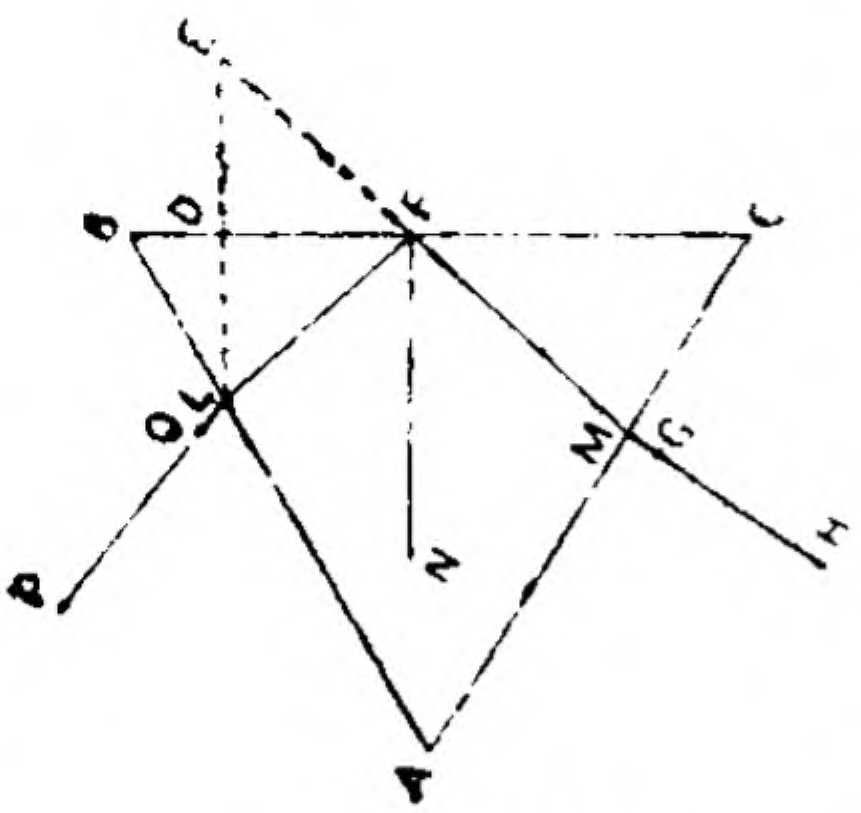


Fig. 99.

Looking through AC fix pins at G and H in a line with the images of P and Q as formed by reflection in the face BC of the prism. Remove the prism and the pins and draw the lines PQ and HG meeting the faces in L and M respectively. The ray PQ enters the prism at L and leaves it at M being totally reflected at F. To find the point F draw LD perpendicular to BC, and produce it to E making DE equal to LD. Join the points E and M by a straight line which will cut BC at F. Join L to F. LFM represents the path of the ray totally reflected in the prism. The ray PQ is refracted along LF. As LF strikes BC at an angle greater than the critical angle for glass, so total reflection takes place and light is reflected along FM.

Draw a normal at the point F, and measure the angles LFN and MFN. Are they equal ? If so, why ?

Repeat the experiment three times.

Record thus :

Angle of incidence	Angle of reflection	Difference

Precautions.—The same as in other pin experiments.

Experiment 71—**To find the critical angle for glass and air and to calculate the refractive index of glass.**

Apparatus.—Glass prism, pins, drawing board, metre rod, and set-squares.

Method.—Place the prism with its apex towards you on the paper which is fixed to the drawing board, and mark its boundary with a pointed pencil. Fix a pin at P, right on the boundary line AC near about its middle as shown in Fig. 100. Placing your eye a little towards the right of B begin moving it towards C till you see the reflected image of the pin P. Continue to move the eye, the pin will become faint and will then disappear. Fix pins at R and S in continuation of the faint image of the pin P. Remove the prism and the pin, and draw a small circle round each point from which a pin is taken. Join RS by a straight line and produce it to meet the face CB in E. At P draw PQ perpendicular to AB and produce it to N making QN equal to PQ. Join the point N to E by a straight line cutting AB in M. Join PM and at M draw ML perpendicular to AB. Measure the angles PML and EML which will be found to be equal to one another, and each one of them will be equal to the critical angle. Make a few more trials and find the mean value for the critical angle.

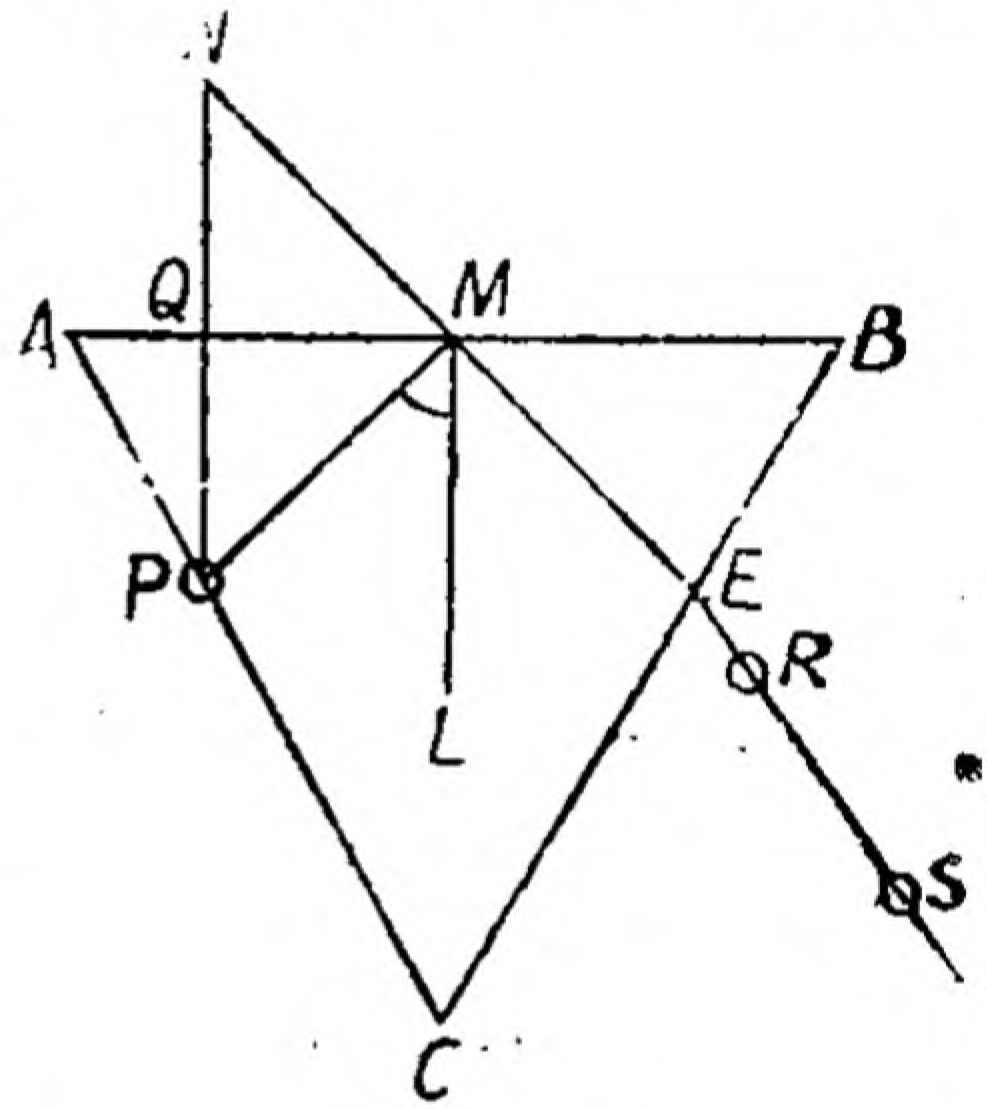


Fig. 100.

Find the sine of the critical angle.

Calculate the refractive index for glass from the relation $\mu = \dfrac{1}{\sin C}$.

Precautions.—Same as in other pin experiments.

Exercises

(1) Trace the course of a ray totally reflected in a cube of glass and find the refractive index of glass.

[*Hints.*—Put an ink dot B on one of the faces of the block, and fix a pin A in contact with the glass surface so that $\angle\theta$ is 30° to 35°. Looking along the direction DC

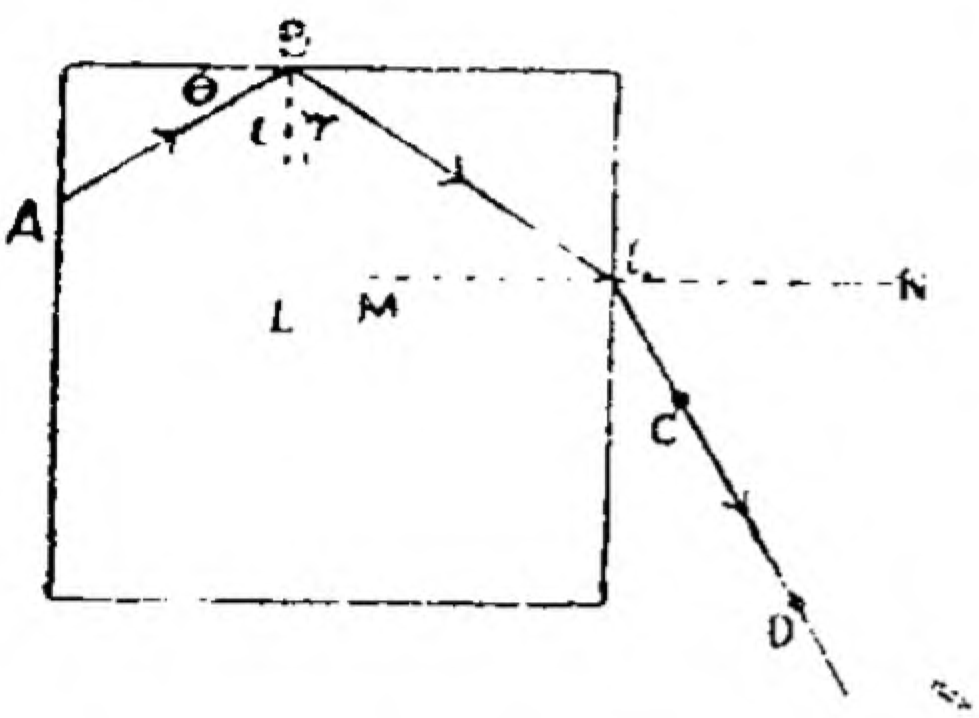


Fig. 101.

fix pins at C and D so that these are in a line with the images of A and B. Join the pin pricks C and D by a fine line which on being produced will cut the surface at E. Join the point E to B. Then ABE is the path of the totally reflected ray in the glass block. Draw a normal at B and measure the angles ABL and EBL. These will be equal. Draw a normal at E and measure the angles NED and BEM and the ratio of the sines of these angles will be the refractive index of glass.

Second Method.—This experiment can also be tried in

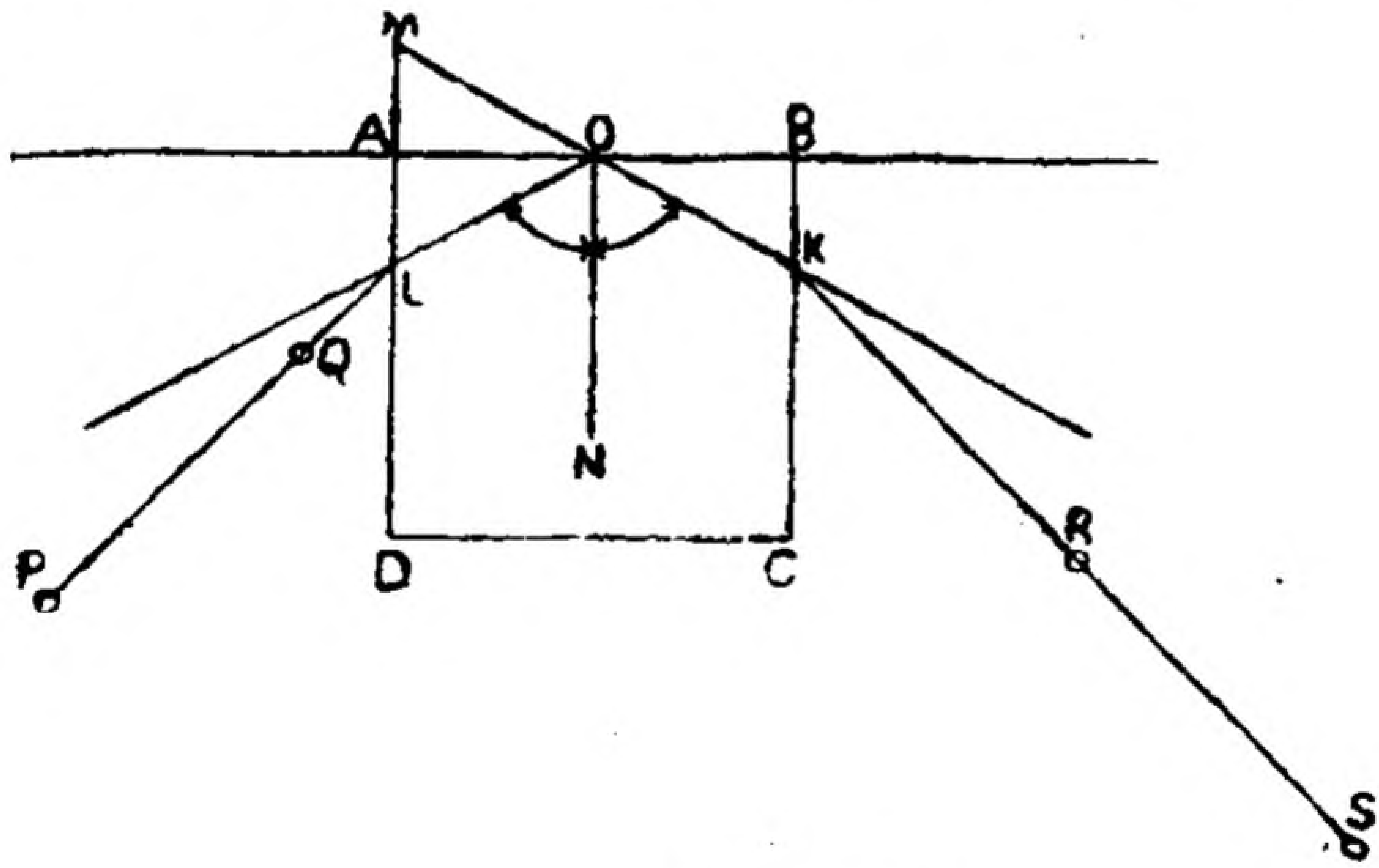


Fig. 102.

another way. Trace the boundary of the block and fix pins at P and Q to mark the direction of the incident ray and looking through BC fix pins at R and S in a line with the images of P and Q. Join PQ and produce it to meet AD at L and let RS meet BC at K. Produce LA to M making AM equal to AL. Join MK cutting AB at O. Draw ON perpendicular to AB. Measure the angles LON and NOK. Are they equal ?

(2) Plot a curve showing the relationship between the angles of emergence and incidence for a ray passing through a given prism.

(3) Using a hollow glass prism, determine the refractive index of water.

(4) Find the refractive index of glass by determining the critical angle with a semicircular glass block.

(5) You are supplied with prism and two convex lenses and a candle or some other source of light; arrange them so as to get a pure spectrum on a screen. Draw the diagram of the arrangement in your note book.

CHAPTER XXIII

SPHERICAL MIRRORS

A spherical mirror is a part of a sphere. There are two kinds of such mirrors :—(*i*) **a concave mirror**, (*ii*) **a convex mirror**. When the silvered surface of the mirror is towards the centre of the mirror, it is a concave mirror, and when the silvered surface is away from the centre, it is a convex mirror.

Definitions :—(1) The centre of the sphere of which the mirror forms a part is the **centre of curvature** of the mirror.

(2) The middle point of the mirror is its **pole**.

(3) The radius of the sphere of which the mirror forms a part is its **radius of curvature**.

(4) The line passing through the pole and the centre of curvature is the **principal axis**. Any other line passing through the centre of curvature is the **secondary axis**.

(5) A number of incident rays parallel to the axis after being reflected from the surface of the mirror converge to a point or appear to diverge from a point. This point is called the **principal focus**.

(6) The diameter of the boundary of the mirrior is its **aperture**.

(7) The distance between the focus and the pole of the mirror is its **focal length**

The focal length of spherical mirror is half of the radius of curvature.

Convention of signs. (1) All distances are measured from the pole of the mirror.

(2) Distances measured to real objects and real images are reckoned *positive*, and those measured to virtual ojects or images are reckoned ***negative.***

Thus the focal length of a concave mirror is positive and that of a convex mirror is negative.

The focal length of the mirror f, the distance of the object from the mirror u and the distance of the image from the mirror v are connected with each other by the relation

$\frac{1}{f}=\frac{1}{u}+\frac{1}{v}$, the distances u, v and f being taken with their proper signs.

Index Error and Index Correction. While determining the focal length of mirrors, we must take into account what is called the *index error*. In such experiments, the wire gauze, and the screen are mounted on their bases, which are not at the right positions. Thus we may measure a distance either more or less than the actual distance.

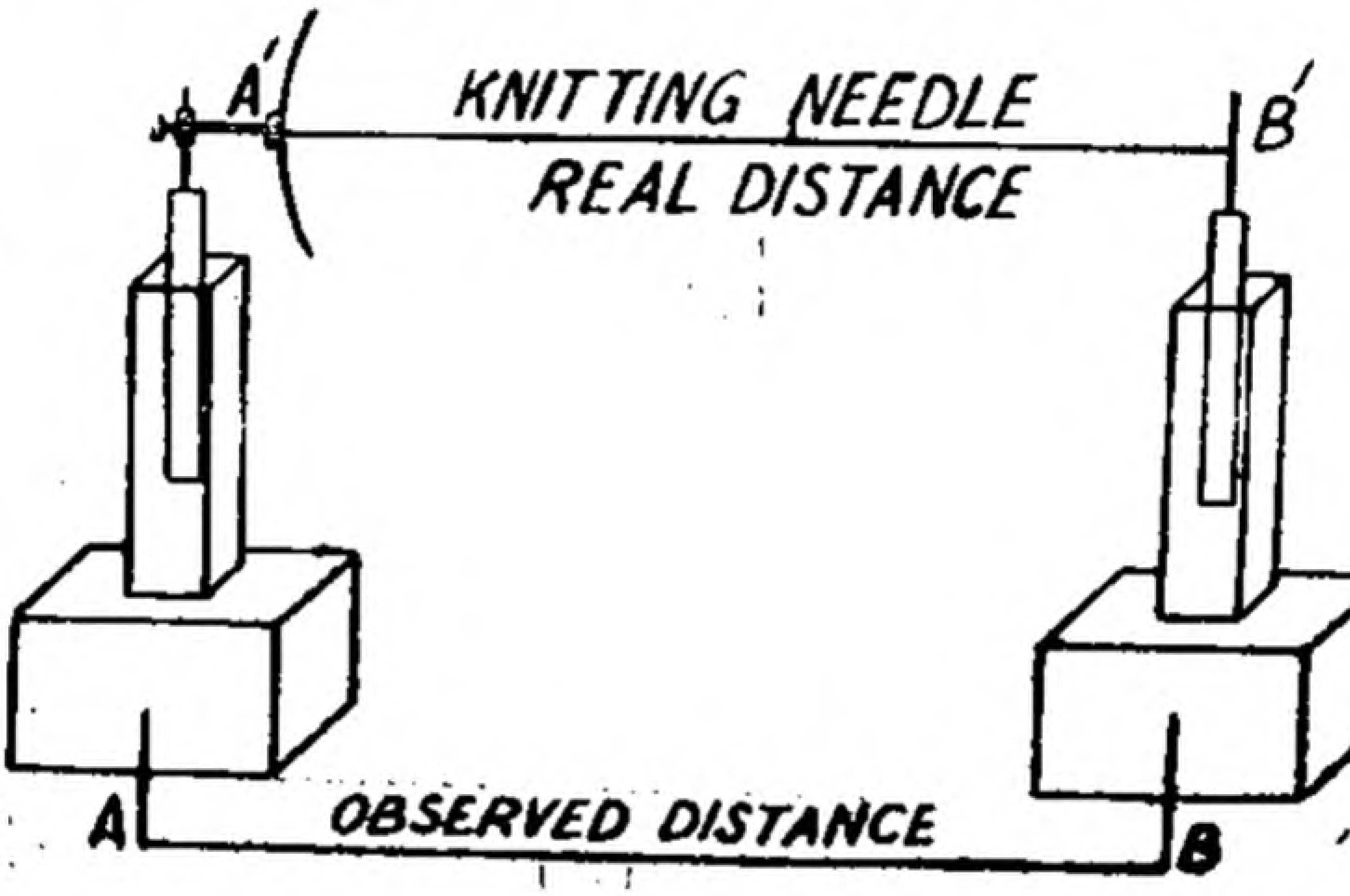


Fig. 103.

In the figure two uprights are shown : one supporting a concave mirror and the other a needle. The index mark on the base of one of the uprights is at A and that on the other at B. The observed distance is AB whereas the actual distance is A′B′. *The difference between the observed distance and the actual distance is the index error.*

But index correction is equal to actual distance minus the observed distance.

It is equal to A B′ minus AB. **The index correction must be added algebraically.**

In order to find **index correction** take a knitting needle, fix it in a universal clamp and make its one end touch the centre of the mirror. Move the other upright till the second end of the knitting needle comes in contact with the screen, or the wire gauze or the pin, as the case may be. Find the distance between the index marks on the two uprights. The *index correction is equal to actual distance (length of knitting needle) minus the observed distance*

(*distance between index marks*), *and it must be added algebraically.*

In experiments, on focal lengths determine *index correction* and not index error, as it will save a lot of botheration. Thus if the length of the knitting needle be 21·0 cms. and the distance between the marks on the uprights 20·0 cms., the index correction would be +1·0 cm. If the distance be reversed, the index correction would become —1·0 cm.

Experiment 72. – **To find the focal length of a concave mirror, using an illuminated wire gauze as the object.**

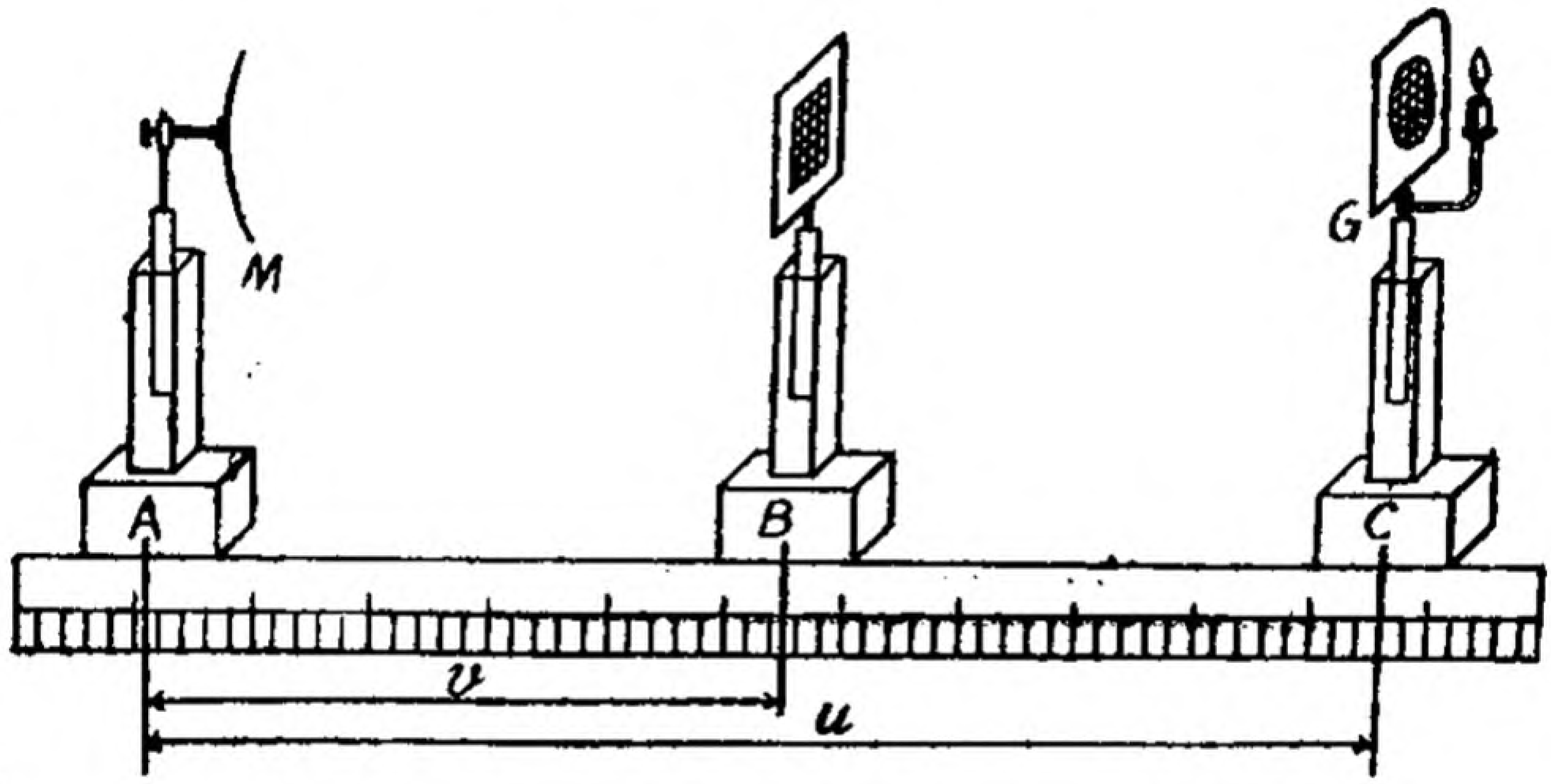


Fig. 104.

Apparatus.—Concave mirror, screen, candle, wire gauze, knitting needle, metre rod, uprights, set-squares.

Method. First determine the focal length of the mirror approximately by throwing a clear image of a distant object on a screen and measuring the distance between the mirror and screen. Mount the mirror, screen, and wire gauze illuminated by a candle on different uprights and arrange them along a metre—stick. Find index correction for the mirror and the gauze uprights, and for the mirror and the screen uprights. Place the wire gauze G at a distance of about 100 or 120 cms. from the mirror M, and the screen near the mirror. By moving the screen backwards and forwards try to get a sharp and magnified image of the gauze on the screen.

Measure the distance of the object and the image from the mirror, and correct each distance for index correction.

Take two more readings by changing the distance of object from the mirror. Interchange the positions of image and object, and by moving the mirror a little backwards and forwards get a sharp and magnified image of the wire gauze on the screen. Measure the distance of the image from the mirror and the distance of object from the mirror and correct each distance by adding the corresponding index correction to it. Take at least three observations when the image is magnified. In this case the wire gauze and not the candle should face the mirror and it should be lowered whereas the screen should be raised.

Record your observations thus :

Approximate focal length=

Length of knitting needle...........(I)

Observed distance between mirror and wire gauze ....(II)

Index correction=(I—II)

Observed distance between screen and mirror.........(III)

Index correction=(I—III).

No. of observations	Position of mirror	Position of gauze	Position of screen	Observed value of u	Correct value of u	$\frac{1}{u}$	Observed value of v	Correct value of v	$\frac{1}{v}$	Focal length $\frac{1}{f}=\frac{1}{u}+\frac{1}{v}$
1										
2										
3										
4										
5										
6										

Mean $f = \ldots$ cms.

Precautions:—1. The image obtained on the screen should be sharp.

2. The axis of the mirror should be parallel to the metre rod and the different uprights should be at right angles to its length.

3. Do not make use of unsteady uprights.

4. Use logarithmic tables for making calculations.

5. Distances of uprights should be read with the help of set squares.

Experiment 73. **To find the focal length of a concave mirror by the parallax method, using (1) one needle, (2) two needles.**

(1) By using one needle :—

Apparatus.—Concave mirror, needle for removing parallax, knitting needle, metre-stick and uprights.

Method.—Determine the focal length of concave mirror approximately by throwing a clear image of the object on a screen and measuring the distance between the mirror and screen. Mount the mirror M and the needle N in uprights

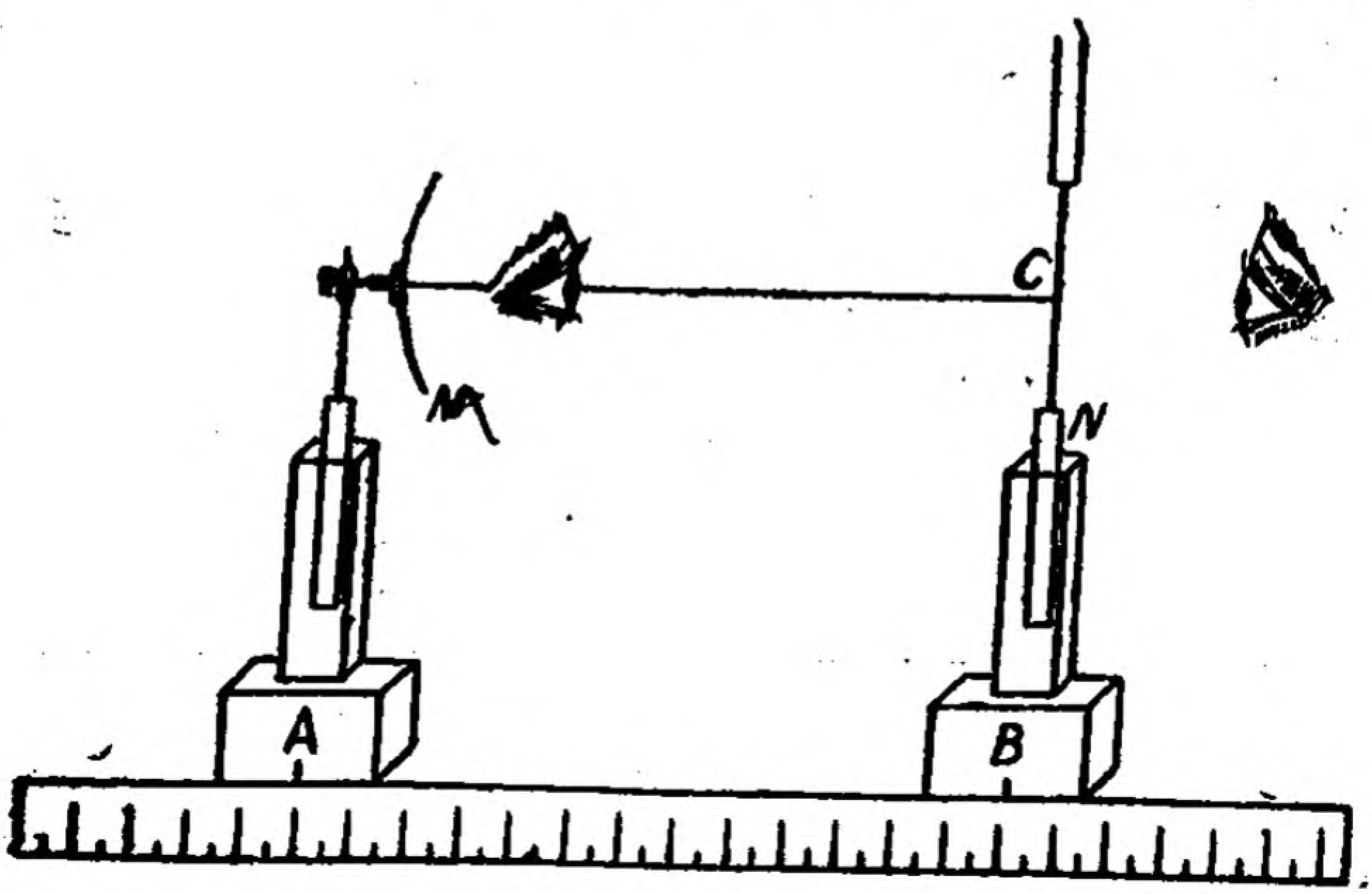


Fig. 105.

and arrange them along a metre stick. Find the index correction. Look into the mirror and try to see the image of the eye.

The line joining the eye and its image is the principal axis of the mirror. Turn the mirror till this line is parallel to the metre rod. Move the needle along the metre rod till you see an inverted image of the needle N formed in the image of the eye and see that the *needle and its image and the image of the eye are in a line with the eye.* Now by moving the eye sideways try to remove parallax between the needle and its inverted image by moving the needle backwards and forwards along the metre rod. In the position of no-parallax the needle and its image will not separate from one another on moving the eye to the right or to the left. The needle N will be at the centre of curvature of the mirror. Measure the distance of the needle from the mirror and add the index correction to it. Half of this distance is the focal length of the mirror. *Remember that the eye should be placed some 30 cms. behind the needle N.*

In certain mirrors it may not be possible to remove parallax near peripheral parts due to *spherical aberration.* In order to overcome this difficulty, stick a paper on the boundary of the mirror having a central groove in it.

Record your observations thus :
Approximate focal length=
Length of knitting needle=
Observed distance between marks on uprights=
Index correction=

No. of obs.	Position of mirror	Position of needle	(Radius of curvature) Distance between needle and mirror	Corrected R	Focal length $\frac{R}{2}$
1					
2					
3					
4					

Mean focal length=

• (2) **By using two needles :**

Take two needles and mount them on uprights. Place the needles in front of the mirror and find index correction (1) for the mirror and the upright carrying needle A and (2) for the mirror and the upright carrying needle B.

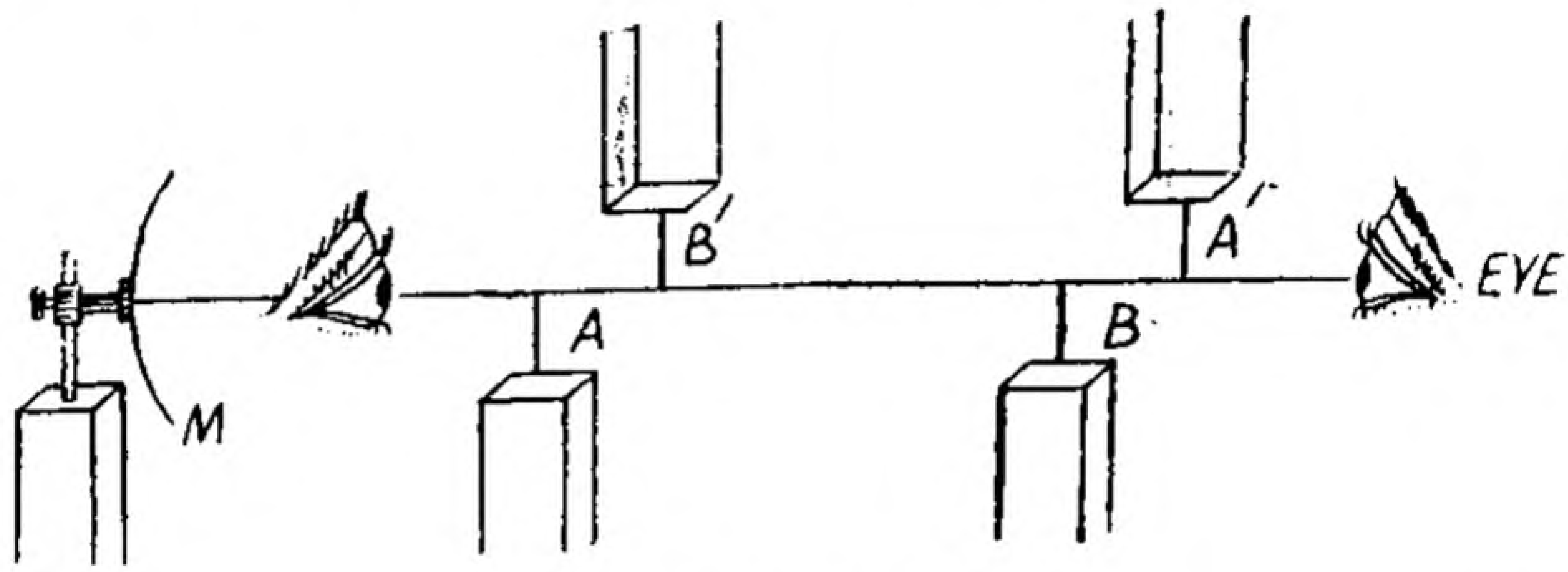


Fig. 106.

Having made the necessary adjustments as explained before, remove parallax between the needle A and the image of the distant needle B by moving B to and fro till its image does not separate from A on moving the eye to the right or left. It will be noticed that in such a position there will also be no parallax between the needle B and the image of the needle A. Measure the distance of the object-needle from the mirror and call it u, and the distance of the image-needle from the mirror and call it v.

The needle A can be treated as the object and B as its image or *vice versa*. By usnig the formula $\frac{1}{f}=\frac{1}{u}+\frac{1}{v}$ or $f=uv/u+v$ calculate the focal length of the mirror. A paper flag on one of the needles is a great help in distinguishing its image from the image of the other needle. Take a number of readings for u and v by means of the two needles.

Record thus :

Length of knitting needle=

Observed distance between needle A and mirror=

Observed distance between needle B and mirror=

Index correction for the mirror and needle A upright=

Index correction for the mirror and the needle B upright=

No. of observations	Position of mirror	Position of object needle	Position of image needle	Value of u	Corrected value of u	Value of v	Corrected value of v	Focal length
1								
2								
3								
4								

Precautions.—1. The height of the needle should be so adjusted that its tip should touch its image, and there should be no overlapping.

2. The eye should be placed at some distance behind the needle with which the image is being located.

3. The axis of the mirror should be parallel to the metre rod and the uprights at right angles to its length.

4. The uprights should touch the metre rod and should not be shaky.

5. Use log table for making calculation.

Exercises

(1) Using a concave mirror, plot a graph between u and v.

(2) Plot a graph showing a relation betweeen $\frac{1}{u}$ and $\frac{1}{v}$ in the case of a concave mirror and calculate the focal length of the mirror.

(3) Find the radius of curvature of the given concave mirror by two methods.

(4) Show that the magnification of an image formed by a concave mirror is directly proportional to v/u.

Experiment 74.—**To determine the refractive index of water with the help of a concave mirror.** K.U. 1961

Apparatus.—Concave mirror, two wooden blocks, needle in a clamp or a retort stand for removing parallax, plumb

line, metre scale and vernier calipers.

Method.—Allow a concave mirror to rest horizontally on two wooden blocks. Clamp a needle horizontally, and find the position of the centre of curvature C of the mirror by removing parallax between the needle and its inverted image. See that the needle and its image just touch each other at the tips. Measure the distance CP of the needle from the pole P of the mirror by means of knitting needles or a long pointer. Repeat your observations three or four times and find the mean of these readings. Now pour a little quantity of water on the mirror so as to form a thin layer on it, and by looking from above remove parallax between the needle and its image. In this case the needle will be brought nearer to the mirror. Measure the distance C′P with the pointer. Repeat your observations three or four times and find the mean of these readings for the distance C′P.

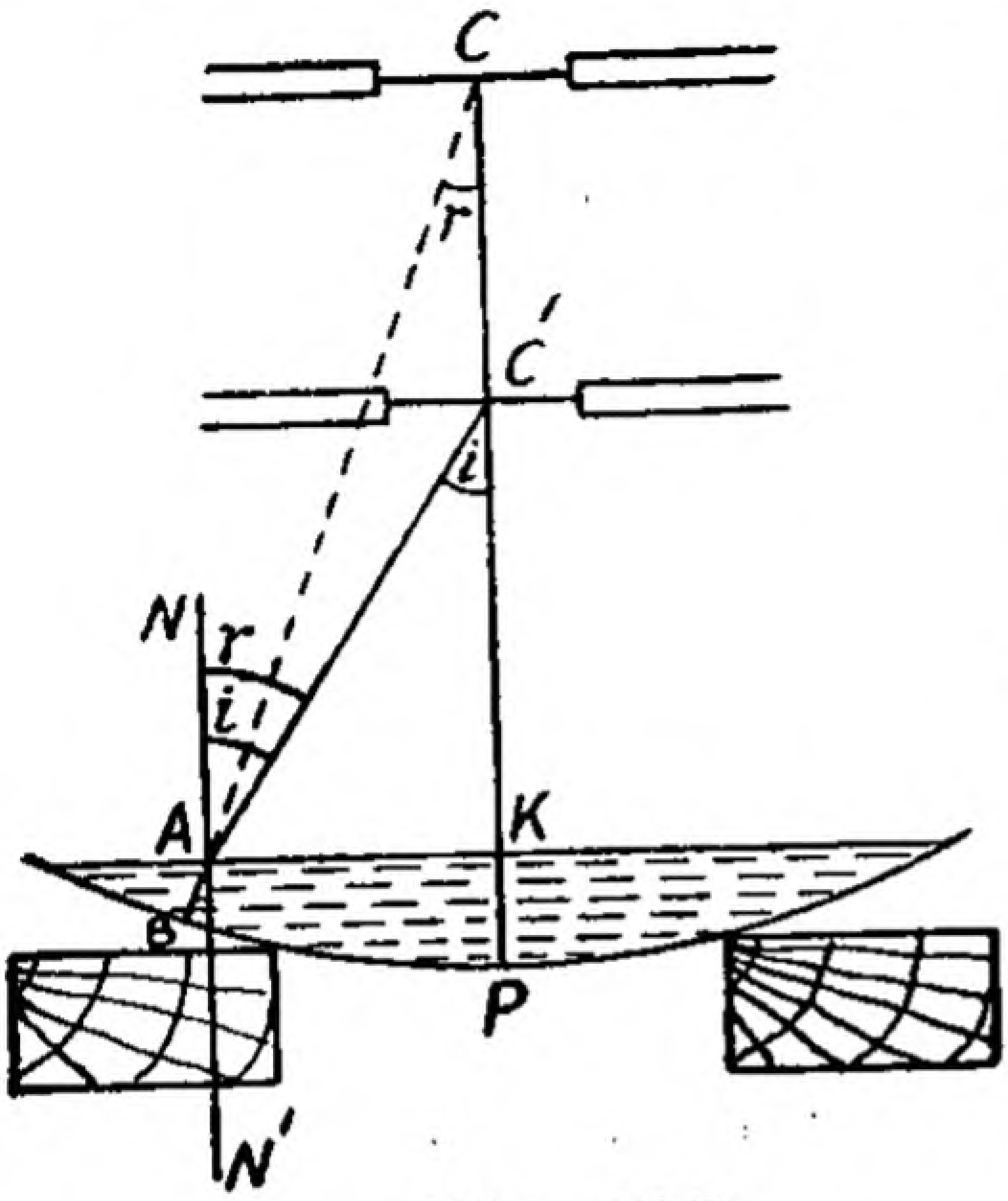


Fig. 107.

$$\mu = \frac{CP}{C'P}.$$

Record thus :

No. of observations	Distance CP without water	Distance C′P with water	$\mu = \frac{CP}{C'P}$	Mean μ
1				
2				
3				
4				

Find the error percentage from the accepted value of μ.

Precautions.—1. The layer of water should be thin.

2. The distance of C′P should be measured from the mirror and not from the surface of water.

3. The mirror should rest horizontally on wooden blocks and should be of small radius of curvature. If the mirror be of large radius of curvature, the mirror should be kept on a low stool.

4. The eye should be kept at a distance of 25 cms. above the needle.

Sources of error :—

(1) It is difficult to adjust the measuring rod at the pole of the mirror.

(2) The thickness of the mirror.

Theory. Let C′A be a ray of light striking the surface of water. It is refracted along AB striking the surface of the mirror at the point B from where reflection takes place. In order that an image of an object lying at C′ be formed at the same place, the ray must strike the surface of the mirror normally, so that light may go back along its own path. In other words, the ray BA on being produced back must pass through C, the centre of curvature of the mirror. Let NN′ be the normal drawn through the point A.

Angle of incidence $= \angle C'AN = AC'K$

Angle of refraction $= \angle BAN' = \angle NAC = ACK$

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin \angle AC'K}{\sin \angle ACK} = \frac{AK}{AC'} \Big/ \frac{AK}{AC} = \frac{AC}{AC'}.$$

As the depth of water is small and B is very near to P, so CA = CP and C′A = C′P.

$$\text{Hence} \quad \mu = \frac{CP}{C'P}.$$

It is very important to remember that the layer of water should be thin otherwise our approximation would not hold.

Exercise.—Determine the refractive indices of glycerine and kerosene oil with a concave mirror.

CHAPTER XXIV

REFRACTION THROUGH LENSES

A lens is a portion of a refracting medium bounded either by two curved surfaces or one curved surface and one plane surface.

Kinds of lenses :—(*a*) Converging or convex lenses.

(*b*) Diverging or concave lenses.

A *convex lens* is thick in the centre and thin at the edges and causes a narrow parallel beam of light to converge to a point called its **focus.**

A *concave lens* is thin at the centre and thick at the edges and causes a narrow parallel beam of light to appear to diverge from a point called its **focus.**

The **optical centre of a lens** is a fixed point on the principal axis such that if a ray of light passes through this point, it does not suffer any deviation.

The **principal axis** of a lens is the straight line passing through the centre of curvature and the optical centre of the lens.

Convention as to signs. (1) All distances are to be measured from the optical centre of lens.

(2) Distances measured to real objects or images are reckoned **positive**, and distances measured to virtual objects or images are reckoned **negative.**

Formula for lenses. The formula $\frac{1}{f}=\frac{1}{v}+\frac{1}{u}$ may be applied to both convex and concave lenses, provided the convention of signs is observed.

In the case of the **convex lens,** as we have to deal with real images so v is a positive distance. Hence for a **Convex lens :**

$$\frac{1}{f}=\frac{1}{v}+\frac{1}{u} \text{ or } f=\frac{uv}{u+v}.$$

Index correction. Like the spherical mirrors, the distances u and v have to be corrected in the case of lenses too. The method of correction is the same as in the case of mirrors.

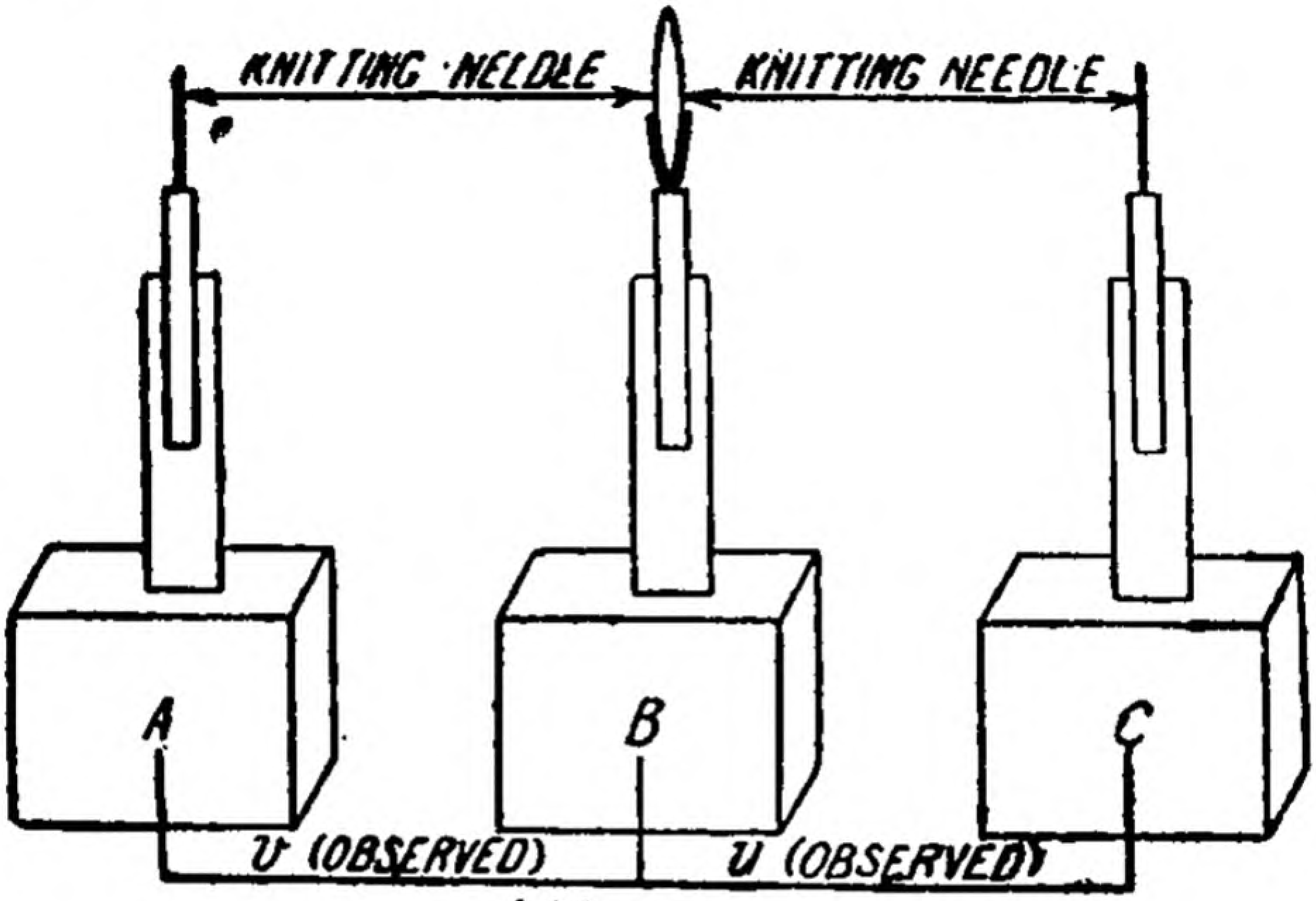


Fig. 108.

Let us first correct the distance u. Take a knitting needle, hold it in a universal clamp and arrange it so that its one end touches the lens and the other the needle serving as an object, as shown in the figure. Measure the *observed distance* between the marks B and C on the two uprights which support the lens and the needle respectively. From the *actual distance* (length of the knitting needle) subtract the *observed distance* (the distance between the marks B and C.)

The result is the index correction which must be added algebraically. The following example will illustrate the point.

Length of the knitting needle=19·0 cms.

Distances between the marks B and C=20·0 cms.

Index correction=19·0—20·0=—1·0 cm.

If the two distances be reversed, the index correction would become +1·0 cm.

Similarly find index correction for v.

Thickness of lens. In the case of the *double convex lens*, distances are to be measured from its optical centre. Hence we must add half the thickness of the *double convex lens* as measured with calipers to the correct values of u and v respectively, (2) In the case of the *plano-convex lens*, the distances u and v should be measured from the convex surface. Hence we must add the thickness of the lens to the distance measured on its plane side.

Magnification produced by a lens. The *linear magnification* produced by a lens is the ratio of the size of the image to the size of the object. It is equal to the distance of the image from the lens divided by the distance of the object from the lens,

$$M=\frac{I}{O}=\frac{V}{U}.$$

Experiment 75. **(1) To determine the focal length of the given convex lens.**

(2) To measure the magnification produced by the given lens and to show that it is equal to the ratio of v to u.

$$\left(\frac{\mathbf{I}}{\mathbf{O}}=\frac{\mathbf{v}}{\mathbf{u}}\right).$$

(3) To draw a graph between u and v, and to find the focal length of the lens from the graph.

Apparatus.—Three uprights, a metre scale, a convex lens, a screen, a knitting needle, a wire gauze, a candle or an electric lamp, a pair of dividers.

Method.—Find the focal length of the given lens approximately by placing it at some distance from the wall and getting a well defined image of some distant object on it. The distance of the lens from the wall will be its focal length.

Find **index correction** for the gauze and the lens uprights, and for the screen and the lens uprights. Place the uprights holding the lens between the other two uprights one of which carries the screen and the other a wire gauze which is illuminated by an electric lamp (frosted type) placed behind it.

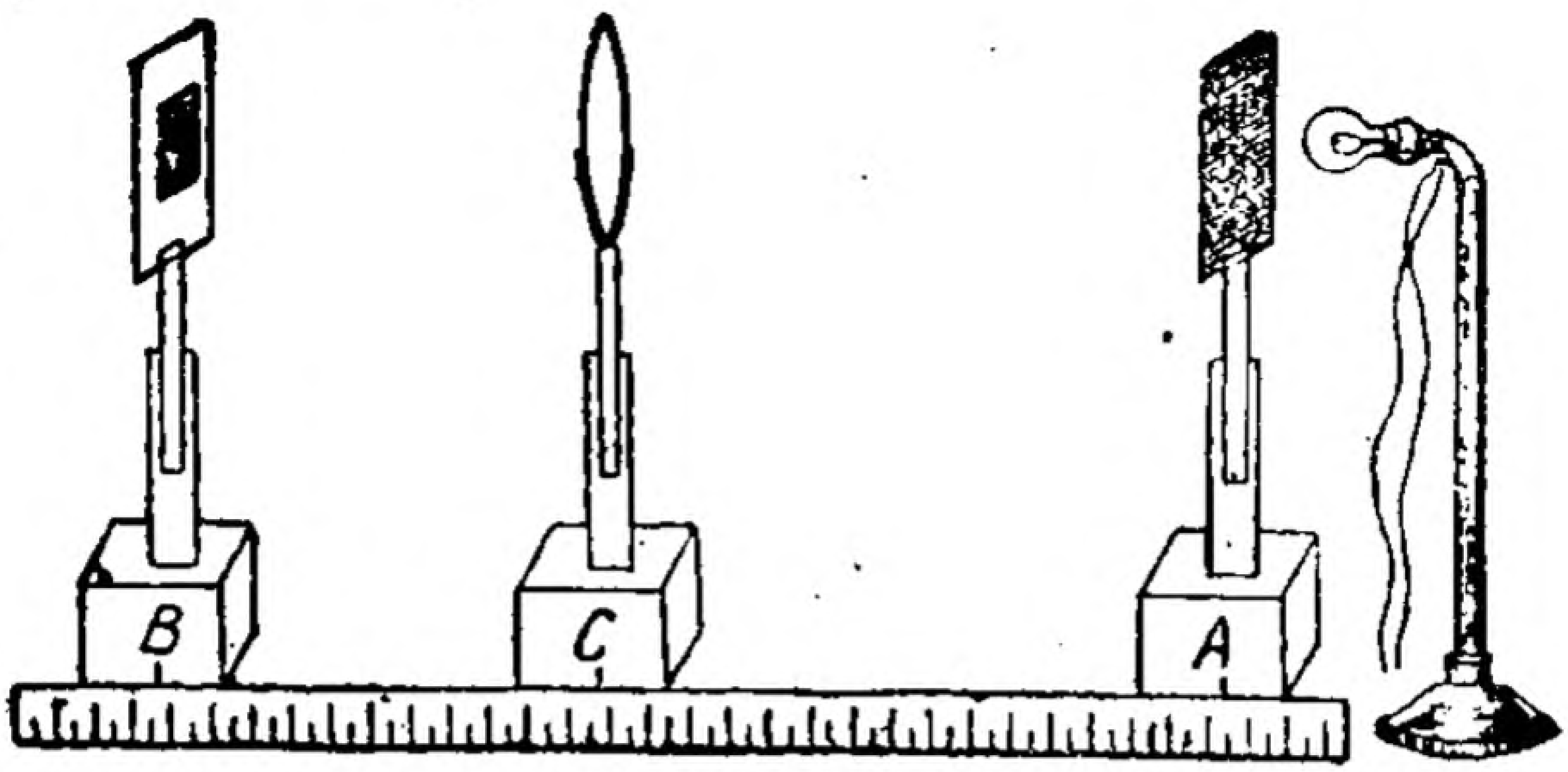


Fig. 109.

Arrange the three uprights along the edge of the metre rod. Get a well defined image of the gauze on the screen. Note the position of each upright on the scale, and find the values of u and v. By applying index correction, correct these distances, and to each corrected distance add half the thickness of the lens. Try the experiment by changing the values of u, and adjusting the position of the screen every time so as to get a sharp image of the object on it. Measure u and v in each case, and correct each distance by adding index correction to it. Calculate the focal length of the lens in each case, and find the mean result.

Record your observations in a tabular form **:**

Length of knitting needle $=$ ...x cms.

Observed distance between the lens and the gauze uprights when one end of the knitting needle touches the gauze and the other the lens $=$ ...y cms.

$\therefore$ *Index correction for u* $=$ $(x-y)$cms.

Observed distance between the lens and the screen uprights when one end of the knitting needle touches the lens and the other screen $=$ ...z cms.

$\therefore$ *Index correction for v* $=$ $(x-z)$ cms.

Thickness of the lens as measured with calipers $=$(1)...(2)...(3)

Mean $=$ ......cms.

No. of observations	Position of gauze	Position of screen	Position of lens	Observed u	Corrected u	$\frac{1}{u}$	Observed v	Corrected v	$\frac{1}{v}$	$\frac{1}{f}=\frac{1}{v}+\frac{1}{u}$	f
1											
2											
3											
4											
5											
6											

Mean focal length of the lens = ...cms.

(2) In order to determine the magnification produced by the given convex lens, get a sharp image of the wire gauze on the screen, and with the help of a pair of dividers, find the distance covered by 6 or 7 meshes of the gauze and of an equal number of meshes in the image. Find also the corrected values of u and v. Find the ratio of the size of image to the size of object, and of the distance of image from the lens to the distance of object from the lens. Take a few more observations in this way, and prove that *the size of the image divided by the size of the object is equal to the distance of the image from the lens divided by the distance of the object from the lens.*

Record thus :—

No. of observations	Size of image (I)	Size of object (O)	$\frac{I}{O}$	Corrected value of v	Corrected value of u	$\frac{v}{u}$
1						
2						
3						
4						

Plot a graph between the values of u and v.

Take the values of u along the axis of x and the values of v along the axis of y, and join the corresponding points as shown in the figure. All the lines will intersect at the same point except for experimental errors. Either of the co-ordinates of the point of intersection is equal to the focal length of the lens. The mean value of the x or y co-ordinate of the point of intersection may be taken as the value of f.

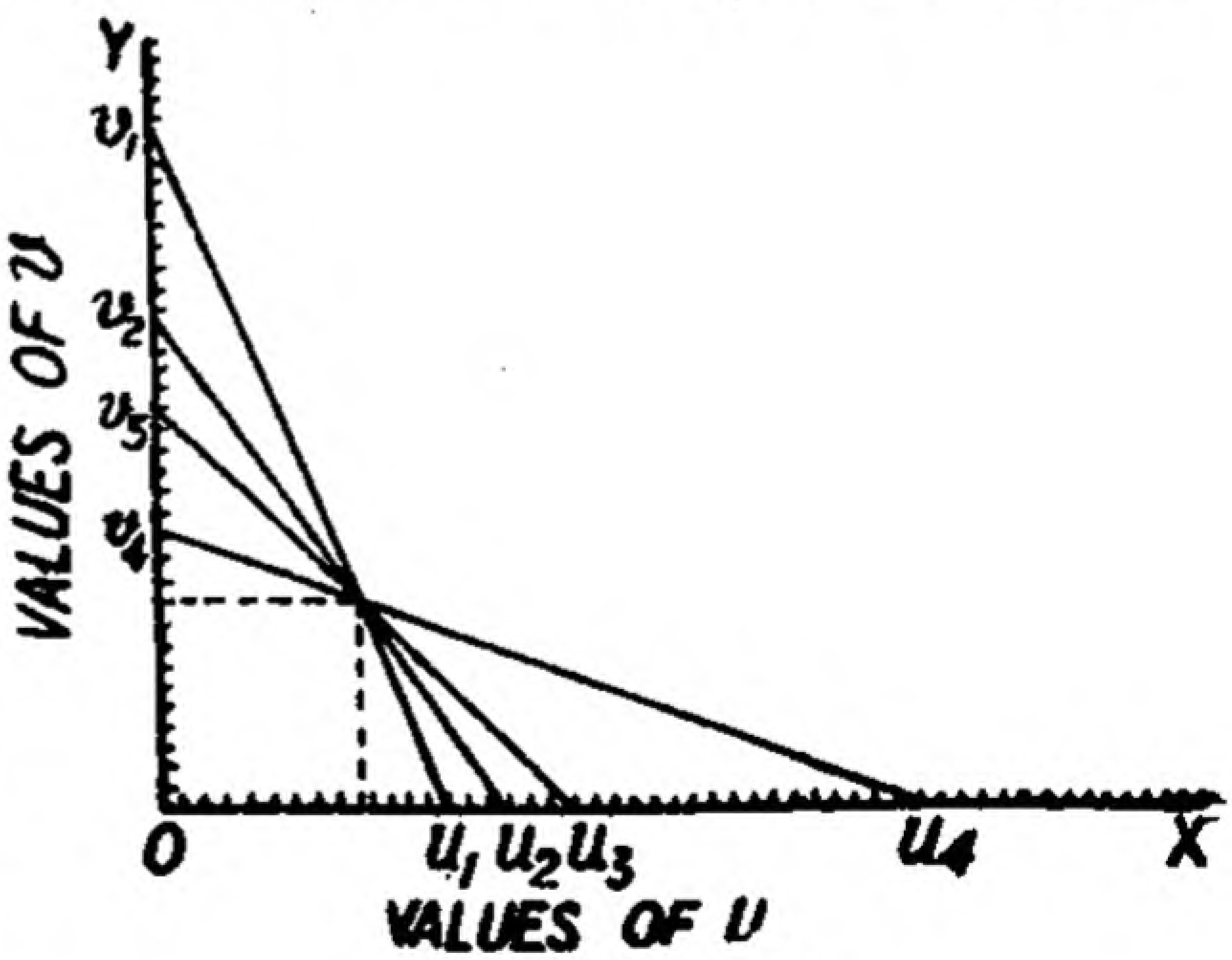


Fig. 110

Precautions.—1. In these experiments the distance of the wire gauze from the screen should in no case be less than four times the focal length of the lens or there will be no image on the screen.

The wire-gauze and not the candle or the lamp is the object.

Experiment 76. **To find the focal length of a convex lens by the method of parallax using (*i*) two needles (*ii*) one needle.**

Apparatus. Three uprights, metre scale, lens, needles for removing parallax, knitting needle, plane mirror, a retort stand.

Method. Two needle method.—Find the focal length of the lens approximately by casting the image of a distant object on the screen and measuring the distance between the screen and lens. Arrange three uprights along a metre scale and let the upright carrying the lens be placed between the other two uprights carrying needles. Arrange the heights of the needles such that the axis of the lens passes through the tips of the needles P and Q and the eye, and it should be made parallel to the metre scale. Determine the index correction for the uprights carrying the lens and the needle P, and also for the uprights carrying the lens and the needle Q. Look through the lens and try to see the inverted image of the pin Q by placing it away from the focal length

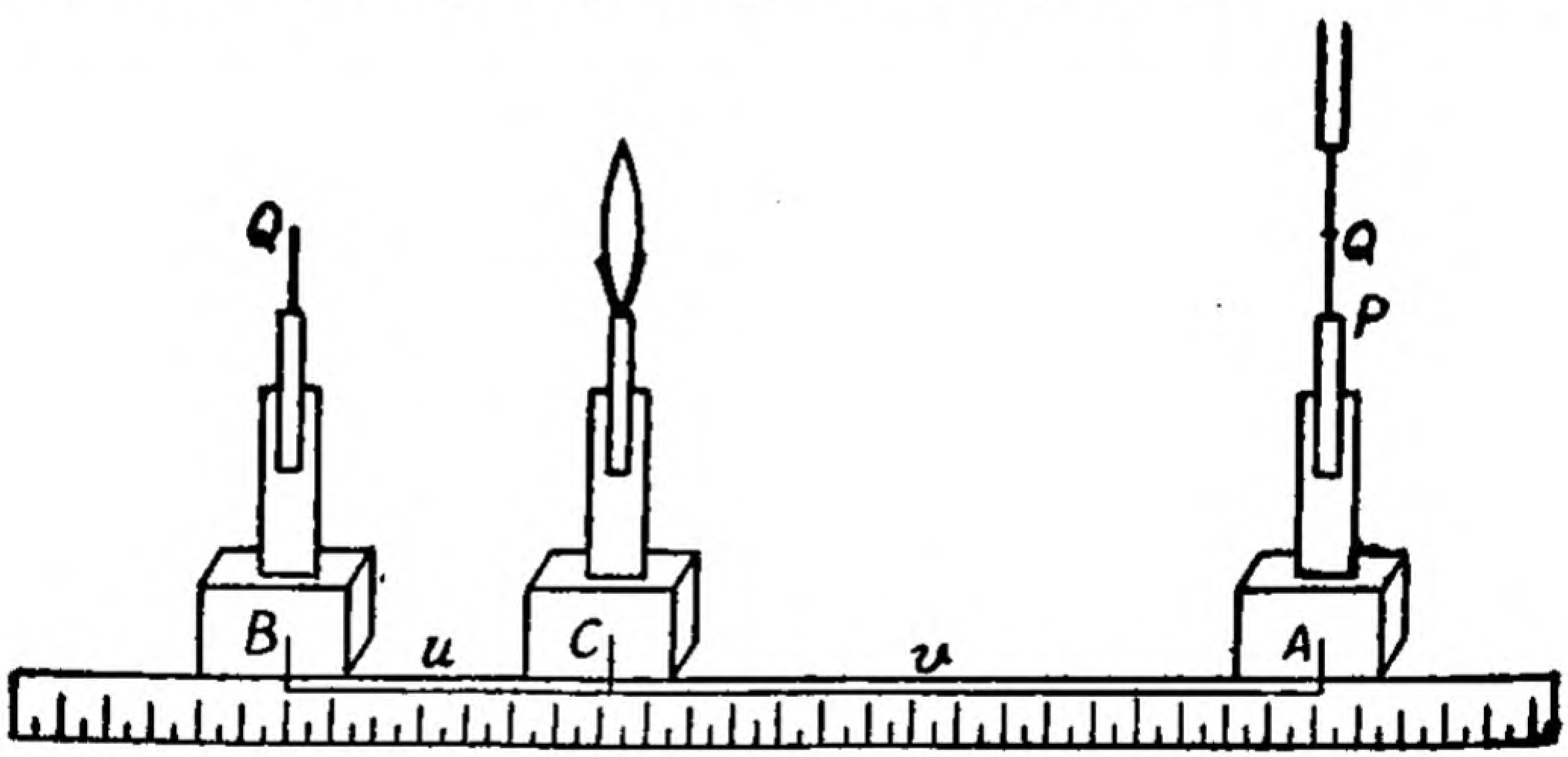


Fig. 111.

of the lens, and adjust the uprights so that the image of Q and the pin P come in a line with their tips touching each other. Try to remove parallax between the needle P and the inverted image of Q remembering that out of the two objects that which moves in the direction of the eye is the farther of the two. If the needle moves in the direction of the eye, move it back, and if the image so moves, move the needle forward till parallax is removed. When parallax is completely removed, note the position of each upright

on the scale, and find the values of u and v. By changing the values of u, find the corresponding values of v. Take a few trials in this way.

By applying index correction, the values of u and v should be corrected. In case the lens used be thick, add half the thickness of the lens as determined with vernier calipers to the corrected value of u as well as v. Calculate the focal length of the lens by using the formula

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} \quad \text{or } f = \frac{uv}{u+v}.$$

Plot a graph between the values of u and v and calculate from it the value of f.

Record your observations in the following way :—

Length of knitting needle =
Observed distance (u) =
Index correction for (u) =
Observed distance (v) =
Index correction for (v) =

No. of observations	Position of lens	Position of object needle	Position of image needle	Observed value of u	Corrected value of u	Observed value of v	Corrected value of v	Focal length
1								
2								
3								
4								
5								
6								

(*ii*) **One needle Method :—**

Method. (*a*) Place a plane mirror behind the lens and parallel to it. Place a needle in front of the lens and remove parallax between it and its inverted image as formed by refraction in the lens and reflection in the mirror. The tips of the needle and its image should just touch each other without overlapping. Measure the distance of the needle from the lens and to it add the index correction with its proper sign and half the thickness of the lens if it be thick. This distance is equal to the focal length of the lens.

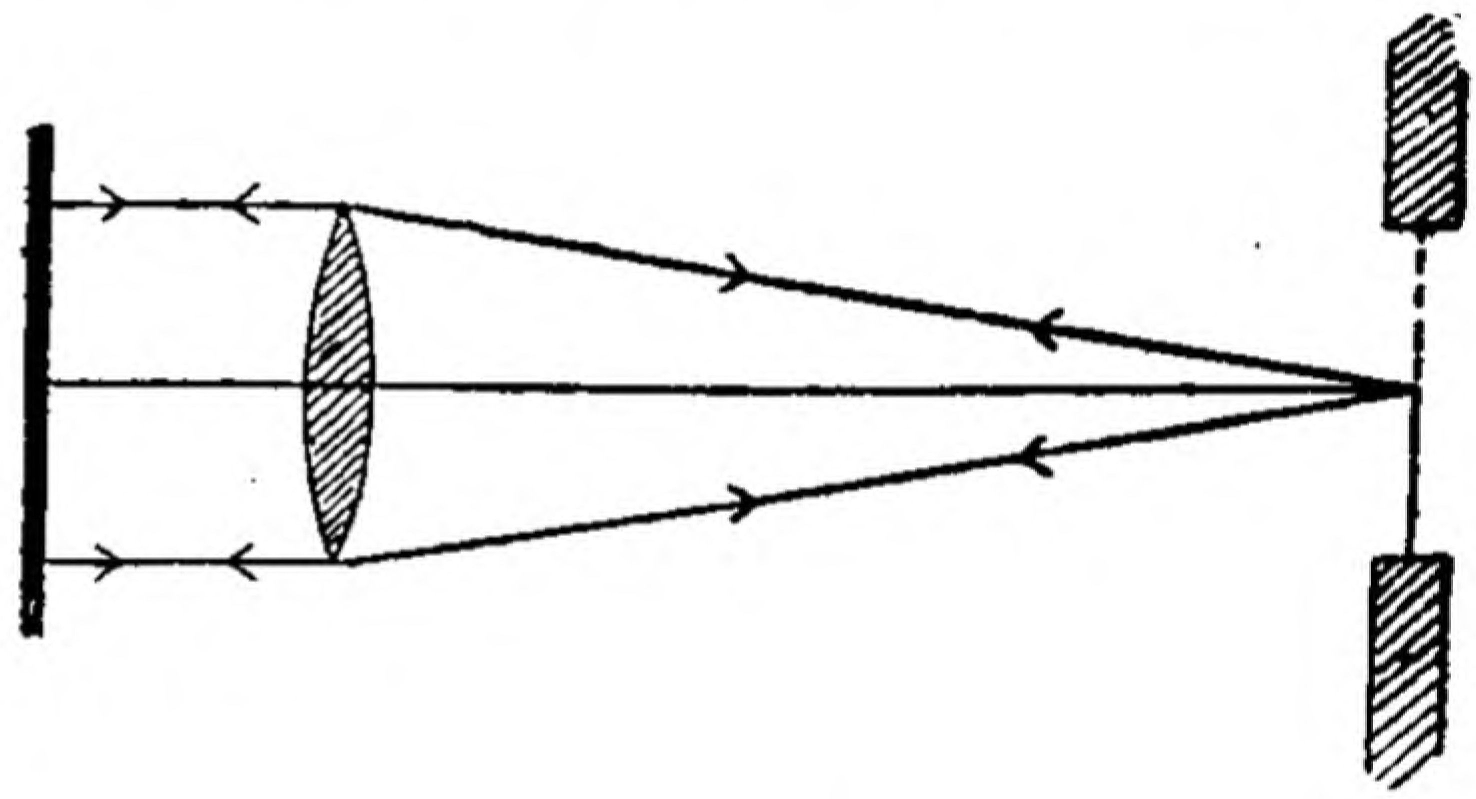


Fig. 112.

In this case, the rays are reflected back along their own path, and, therefore, strike the mirror normally. The rays leave the lens as a parallel beam and therefore come from the focus of the lens.

This method is useful in the case of long focus convex lenses.

Record your observations as follows :—

Length of knitting needle =

Observed distance =

Index correction =

No. of observations	Position of lens	Position of needle	Distance between lens and needle (Focal length)	Corrected focal length
1				
2				
3				
4				

(*b*) *This method (one needle) can be improved so as to eliminate the thickness of lens.*

After having removed parallax from one side of the lens as explained above, note the position of the upright carrying the needle. Without disturbing the lens, move the mirror to its other side, and again remove parallax by bringing the same needle to this side. Note the position of the needle again. The distance between the two positions of the needle upright is equal to twice the focal length of the lens. Half of this distance is the focal length of the lens, which is automatically corrected for index error and thickness of the lens.

Record your observations thus :—

No. of observations	Position of lens (fixed)	Position of needle on one side	Position of needle on the other side.	Distance between two positions ($2f$)	f

Precautions:—1. In experiments on parallax the tips of image and object should touch and not overlap each other.

2. The eye should be placed at a distance of 30 cms. behind the needle with which the position of the image is located.

3. The axis of the lens should be parallel to the metre stick and the various uprights should be at right angles to its length.

4. Do not make use of unsteady uprights.

5. Do not place the needle within the focus of the lens otherwise you will get a virtual and upright image. Always remove parallax with a real inverted image of the needle.

6. For accurate work the thickness of the lens must be taken into account.

7: It is better to find index correction at the end of the experiment.

8. The mirror should be held quite parallel to the lens.

Experiment 77. **To find the focal length of a concave lens by combining it with a convex lens.**

Apparatus.—Concave lens, convex lens of suitable focal length so that on combining it with the concave lens, the combination behaves as a converging lens, uprights, needles, a knitting needle, metre-stick.

Method.—Find the mean focal length of the convex lens by the parallax method using a plane mirror and a needle. Call it f_1. Now combine the convex lens with the concave lens, and find the mean focal length of the combination of lenses by the parallax method with the help of a needle and a plane mirror. Let F denote the focal length of the combination of lenses. Now $\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}$ where f_2 denotes the focal length of the concave lens which can be easily calculated by substituting in the formula the values of F and f_1.

Experiment 78.—**To find the refractive index of water by using a convex lens and a plane mirror.**

Apparatus.—A convex lens, a plane mirror, a needle for removing parallax, knitting needle, a beaker, a plumb line, a metre rod, vernier calipers, spherometer.

Method.—Place the convex lens on the plane mirror and find the position of the focus of the lens by removing parallax between a needle held horizontally above it and its image. Measure the distance of the needle from the mirror with a plumb line and from it subtract half the thickness of the lens, as measured with calipers. This gives the focal length of the convex lens. Call it f_1, find the mean focal length.

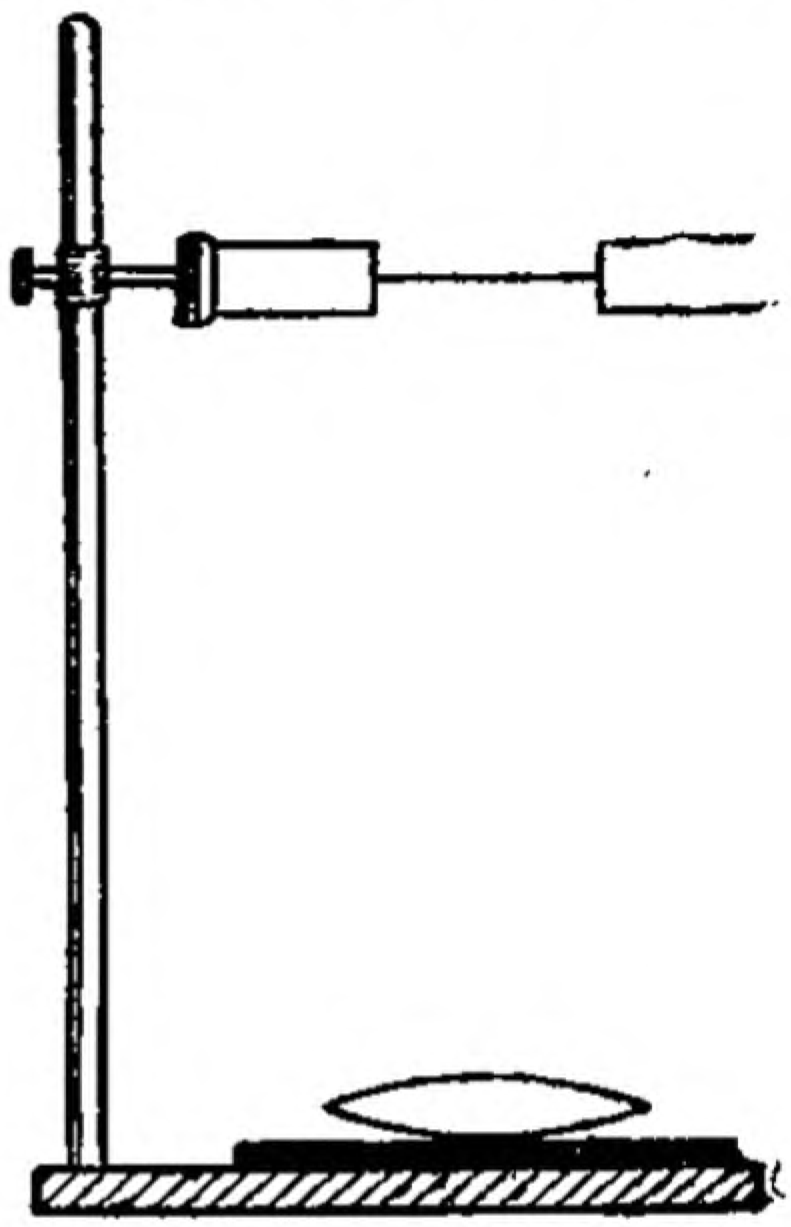


Fig. 113.

Pour a little quantity of water on the mirror and place the convex lens on it. The liquid lens so formed is plano-concave whose concave surface is in contact with the convex surface of the lens and the plane surface in contact with mirror. Again remove parallax between the needle and its image. Measure the distance of the needle from the mirror and subtract half the thickness of the lens from this distance. This gives us the focal length of the combination of liquid concave lens and the convex lens. Let this focal length be denoted by F. Take a few trials and find the mean focal length. The focal length of the liquid lens (f_2) can be calculated from the equation

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}.$$

The liquid lens is a plano concave lens. The curvature of the conacve lens is the same as that of the convex side of the convex lens which is in contact with it. Find the radius of curvature of the convex lens with a spherometr. The formula for finding the radius of curvature is $R=\frac{l^2}{6h}+\frac{h}{2}$ where l denotes the distance between the legs of spherometer. The distance (l) between the legs of the sphero-

meter should be measured carefully as R depends upon the square of l.

Calculate the refractive index of water from $\frac{1}{f_2}=(\mu-1)\frac{1}{R}$ where μ is the refractive index of water, and R the radius of curvature of the lens.

Record your observations thus :—

Thickness of lens=(1)......(2)......(3) Mean= cms.
Distances between the legs of spherometer

=(1) (2) (3) (4) (5) (6) mean= cms.

$h=$ —mean= — cms.

$$R=\frac{l^2}{6h}+\frac{h}{2}= \text{ cms.}$$

No. of observations.	Focal length of convex lens f_1	Focal length of combination F	Focal length of liquid lens $\left(\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}\right)$	R	$\mu=\frac{R}{f_2}+1$

Exercises

(1) Plot a curve showing relationship between the size of an image (I) and its distance from the lens (v).

(2) Find the focal length of the lens formed by filling the given watch glass (a) with water (b) with benzene (c) with toulene. State which of the liquids has the greatest refractive index.

[*Hint.*—The focal length can be determined by placing the watch glass(supposed thin) containing the given liquid on a plane mirror, and removing parallax between a needle and its inverted image. The needle will be at the focus of the liquid lens. The liquid here forms a plano-convex lens the radius of curvature of the convex surface is the same as that of the concave surface of the watch glass. Calculate μ from the formula $\frac{1}{f}=(\mu-1)\frac{1}{r}$.

(3) You are supplied with a convex lens, two needles mounted on stands, and a metre rod; how would you prove the formula expressing the relation between the distances of an object and its real image from the lens ?

CHAPTER XXV

OPTICAL INSTRUMENTS

Astronomical Telescope.—It consists of two convex lenses (1) an **objective or object glass** of large focus and large aperture, (2) and an **eye-piece** of small focus and small aperture. The objective which is directed towards the distant object forms a real, and inverted image at its focus. The eye piece is placed in such a position that the image formed by the objective is within its focus and, therefore, a virtual, upright and magnified image is formed which can be brought at the distance of distinct vision. The final image is inverted with respect to the object. If the image formed by the object glass is brought at the focus of the eye-piece, the final image will be at infinity.

The length of the astronomical telescope is equal to the sum of the focal lengths of the objective (F) and the eye-piece (f), when it is normal adjustment, and its magnifying power is equal to F/f.

Experiment 79.—**To set up the model of astronomical telescope.**

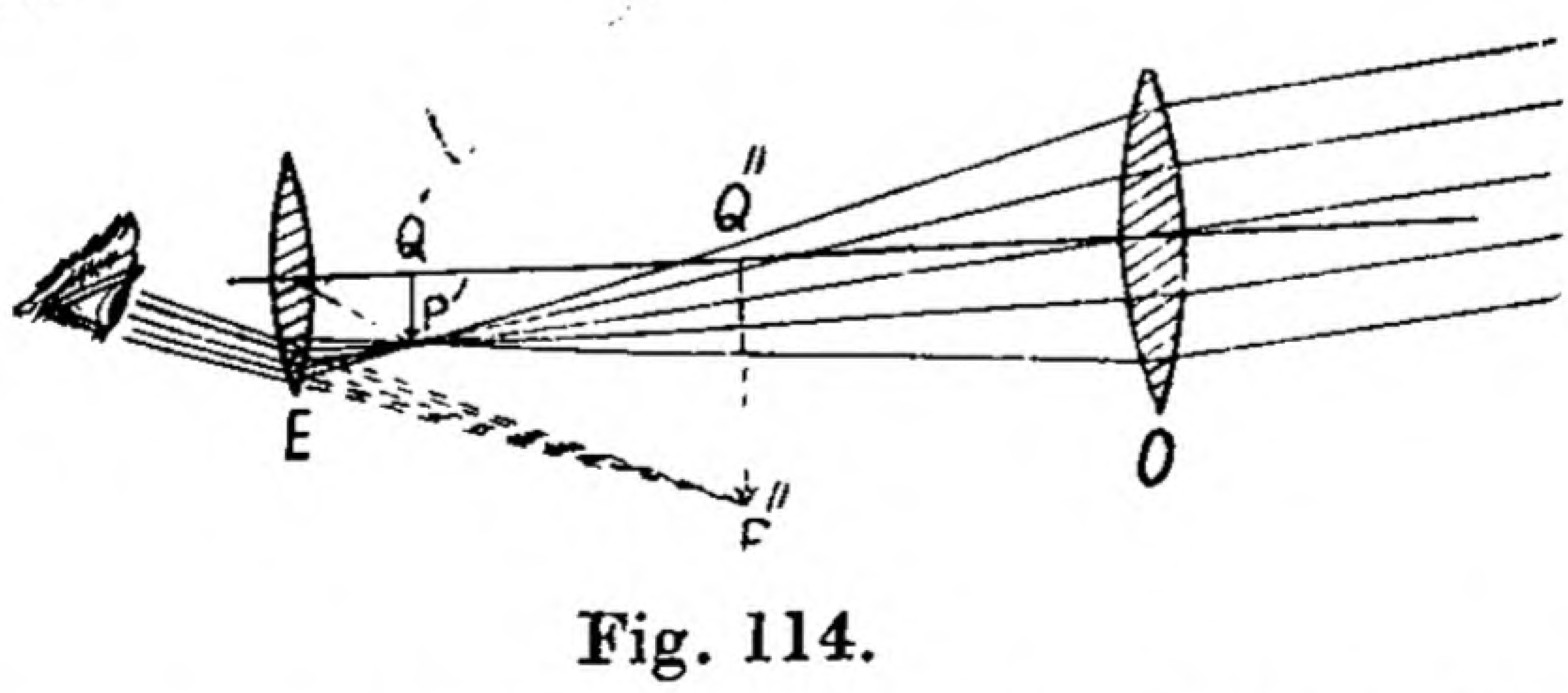


Fig. 114.

Apparatus : A double convex lens of long focal length not over 40 cms. to serve as the objective, a double convex lens of focal length 5 or 12 cms. to serve as the eye-piece, a noedle for removing parallax, uprights, a metre scale.

Method(*a*). *Focal length of the lenses.*

Take one of the lenses, and mount it in an upright. Focus some distant object on a screen with the help of the given lens. Measure the distance between the lens and the screen, and record this focal length. Similarly find the focal length of the other lens, and record it. Take the mean of several observations. You can find the focal length of lenses by one needle method also.

(*b*) *Uses of the lenses.*

Looking through the objective remove parallax between the inverted image of some bright distant object and a needle. When the parallax will be removed, the image of the distant object and the needle will not separate on moving the eye to the right and left.

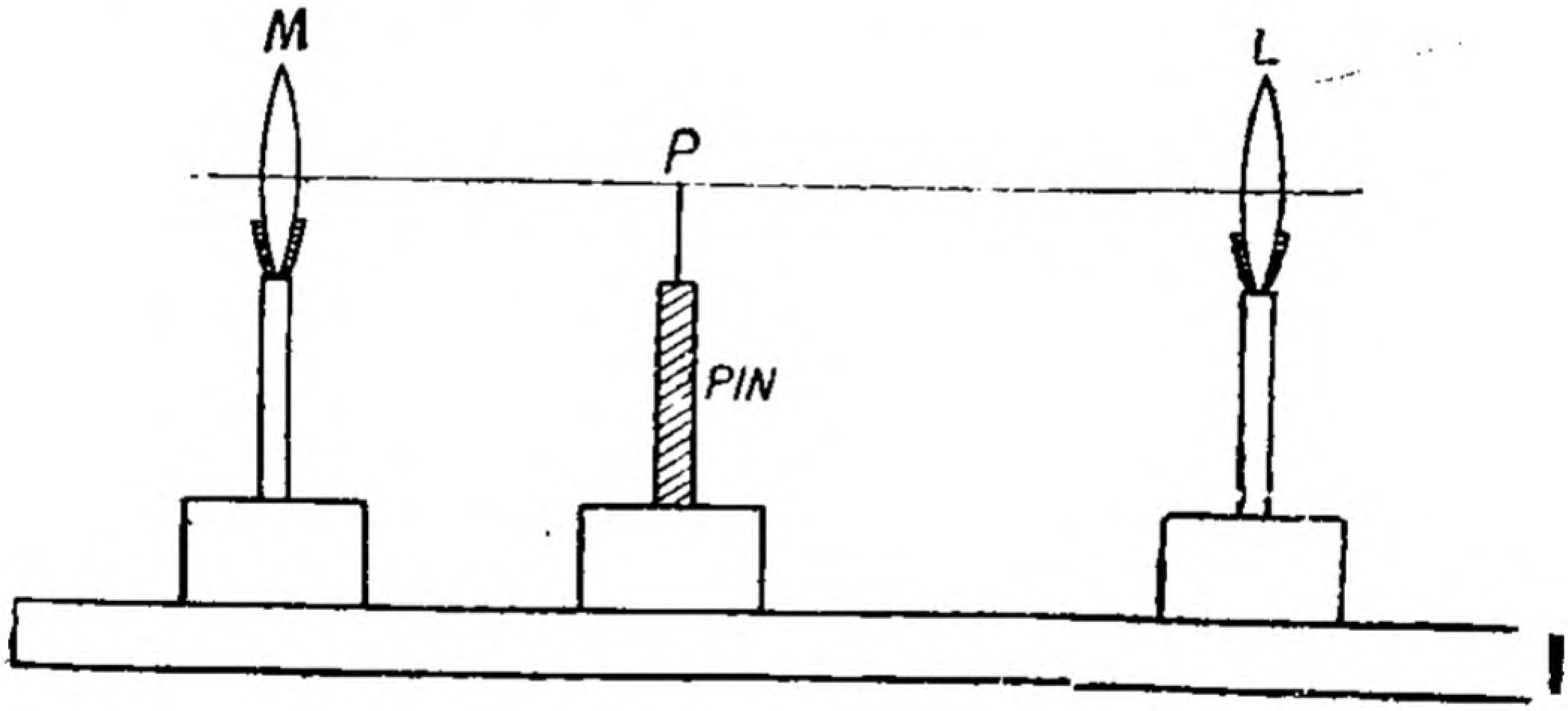


Fig. 115.

Leaving the objective focussed, use the eye-piece on the other side of the needle, so that the centres of the two lenses are on the same horizontal line. Move the eye-piece and adjust its distance so that the needle is in focus. Remove the needle. Move the eye-piece till you can see distinctly through it the image of the distant object. This is how we focus the eye-piece of a telescope on the image of a distant object. Measure the distance between the objective and the eye-piece. In Fig. 115 L stands for the objective, M for the eye-piece, and P represents the position of the image as formed by the objective.

Record your observations as follows :—

Focal length of objective F	Focal length of eye-piece f	$F+f$	$\frac{F}{f}$

Draw a diagram showing the path of rays through the lenses.

(c) Magnifying power of the telescope.

With one eye look through the telescope at a distant scale and with the other eye look at the scale directly. The magnified scale as seen through the telescope should appear superimposed upon the real scale. Find the number of divisions of the scale as seen by the naked eye that coincide with one division as seen through the telescope. This gives us the magnifying power of the telescope.

Compare this result with the magnifying power as obtained by dividing the focal length of object glass with the focal length of eye-piece.

Galileo's Telescope. It consists, like the astronomical telescope, of an objective which is a double convex lens of long focal length. The eye-piece is a double concave lens which is placed between the objective and the image formed by it so that the latter may lie within, or for normal adjustment at its focus.

The optical action of the arrangement will be clear from the diagram.

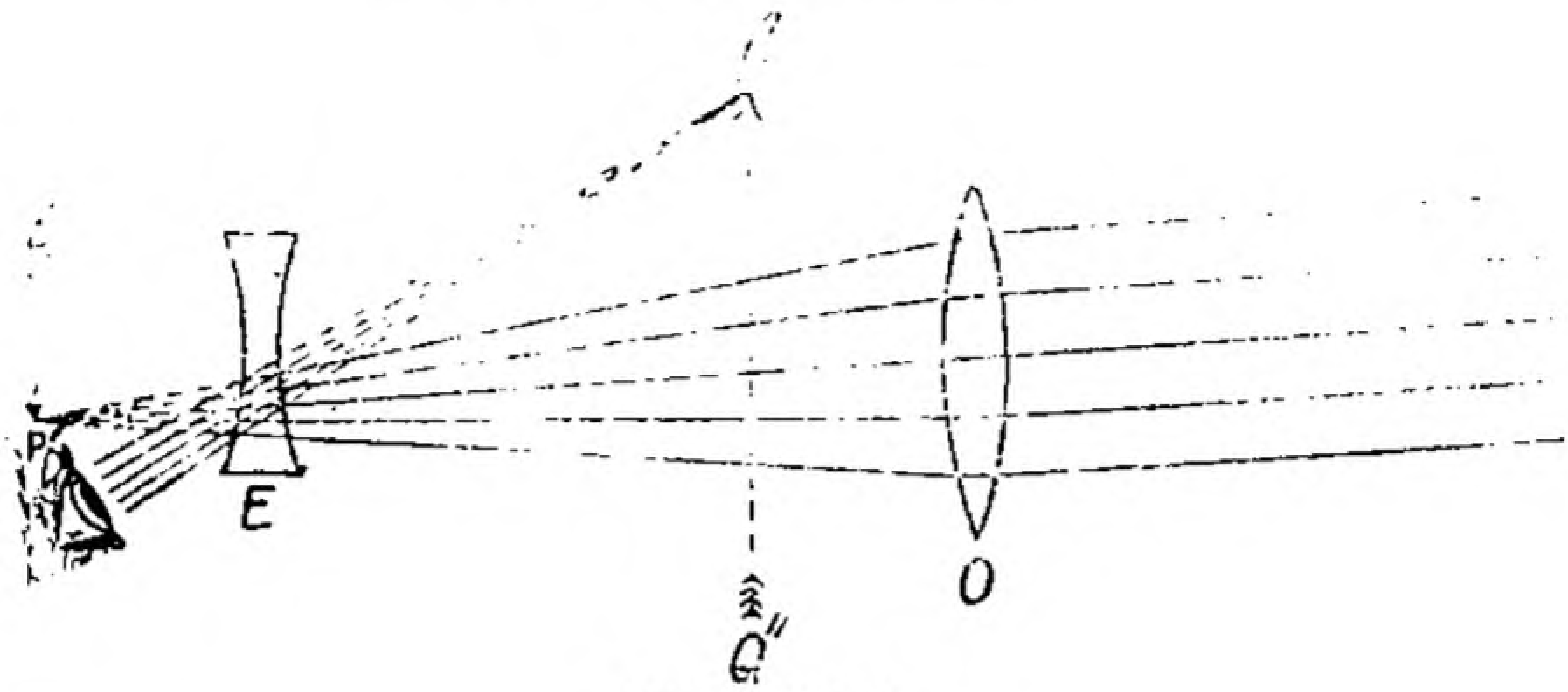


Fig. 116.

In the absence of the eye-piece a real image of the distant object will be formed by the objective at its focus. But when the double concave lens is interposed between the objective and its focus, the rays of light are made to diverge and a virtual and upright image of the distant object is formed. The function of the eye-piece is to magnify the image formed by the objective. The magnified image is erect and the telescope is suitable for terrestrial purposes.

Experiment 80.—**To set up the model of Galileo's Telescope.**

Apparatus.—Convex lens of focal length 40 cms. to serve as object glass, concave lens of focal length 12 cms. to serve as eye-piece, uprights, a needle for removing parallax and a metre scale.

Method.—Find the focal length of the given lenses. The focal length of concave lens can be determined by combining

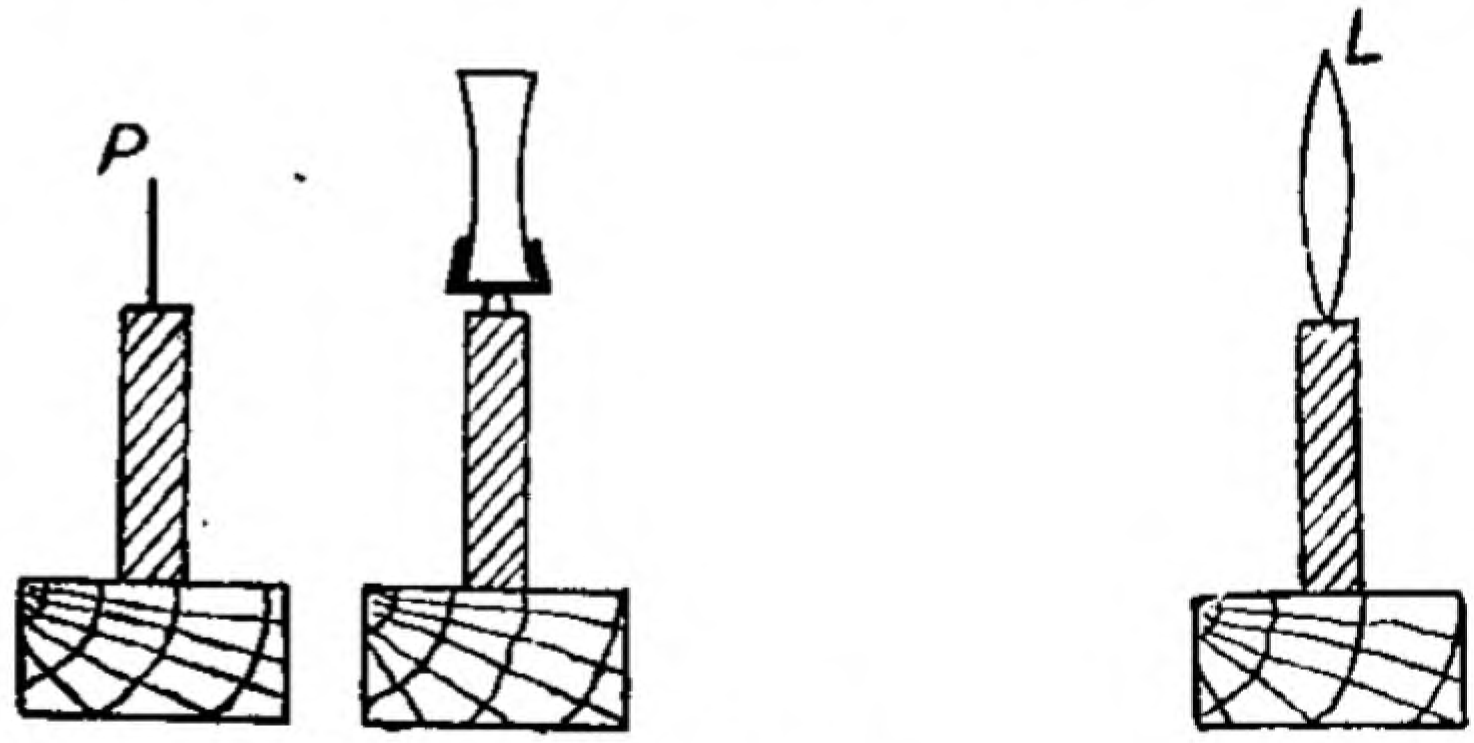


Fig. 117.

it with a convex lens. Place the convex lens L of long focal length in an upright and find its focus by a pin P by removing parallax between it and the image

telegraph post. Between P and L place the concave lens so that P is at its focus. Remove the pin P and look through the concave lens by placing the eye close to it towards the objective, you will get an erect image of the distant object. By moving the concave lens a little backward or forward you can get the best position from where you can get sharp images of distant objects.

This is the principle of Galileo's telescope.

Measure the distance between the two lenses and show that it is equal to the difference of the focal lengths of the objective and the eye-piece. Calculate F/f.

Draw a diagram showing the path of rays through the lenses.

Tabulate your result as follows :—

Focal length of objective F	Focal length of eye-piece f	$(F-f)$	Magnification $\frac{F}{f}$

Reflecting Telescope.—

A reflecting telescope consists of a concave mirror C from which rays of light are reflected, and these rays would converge to a focus in front of it if there were to be no plane mirror M But in the presence of the mirror M the rays converge to the eye piece consisting of a double convex lens or two plano-convex lenses with their convex surfaces turned towards each other. As this image comes within the focus of

the eye-piece, so a virtual, upright and magnified image of the distant object is formed.

A reflecting telescope takes many forms but the commonest form is shown in the diagram.

The biggest reflecting telescope is at Mount Wilson Observatory with a reflector 100 inches in diameter.

Advantages of a reflecting telescope over a refracting one :—

(*a*) There is no chromatic effect, (*i. e.*, images are non-coloured).

(*b*) By making use of a parabolic mirror spherical aberration can be entirely got rid of (or the images are not distorted).

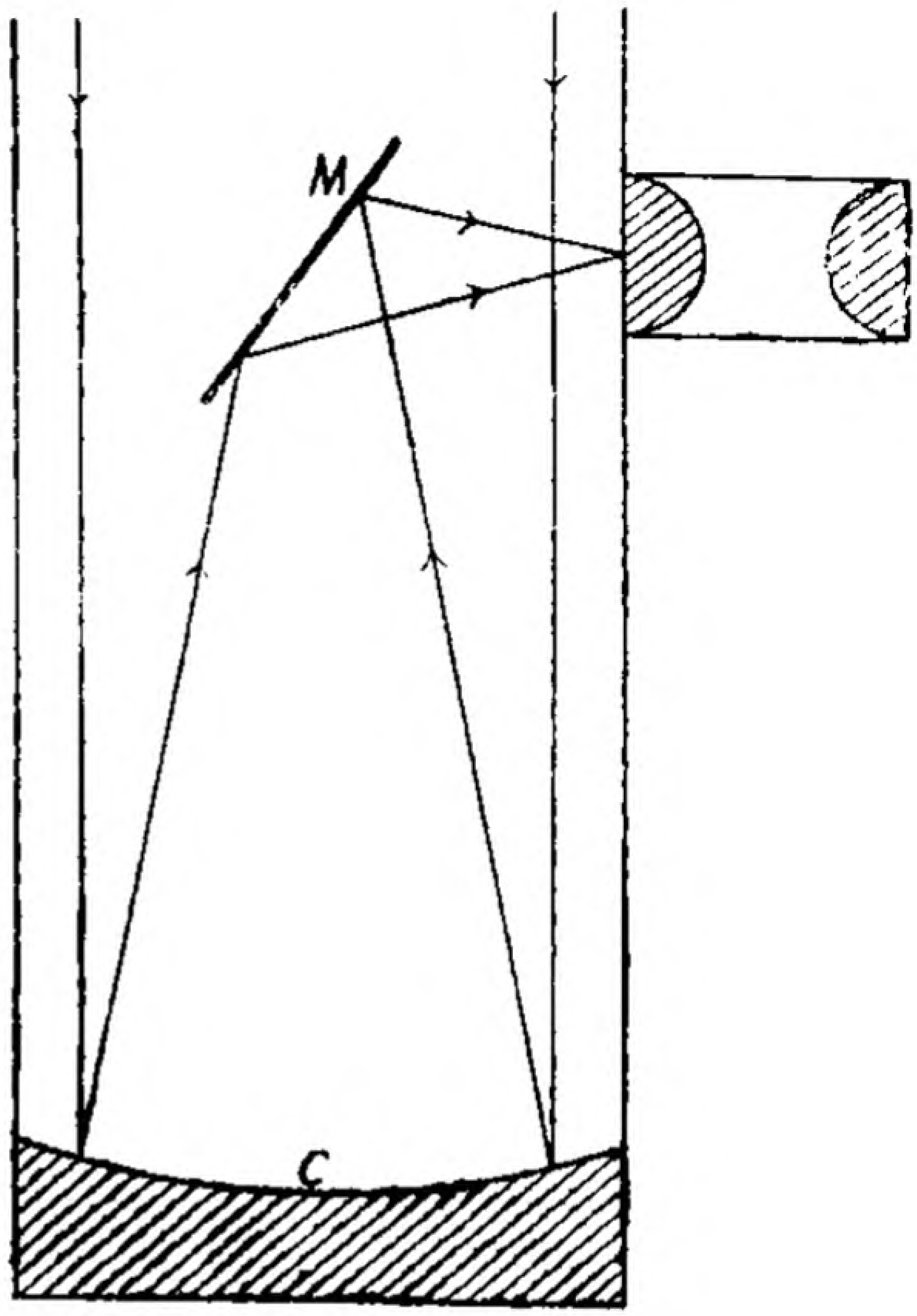


Fig. 118.

Experiment 81.—**To set up the model of a reflecting telescope.**

Apparatus :—A concave mirror, a plane mirror, a needle and a convex lens.

Method.—Place the concave mirror facing some distant object and by moving a paper to and fro along its axis try to get the image of the object on it. This gives us the position of the focus of the mirror. Note this position. Between the concave mirror and its focus place a plane mirror inclined to the axis at an angle of 45°. The rays of light instead of coming to a focus in front of the mirror are reflected downwards and converge in this direction. By means of a needle remove parallax between it and the image of the distant object. Now take a convex lens and let the needle come within its focus so as to get a virtual, upright and magnified image of the needle. On removing

the needle and looking through the lens, you will get a distinct image of the distant object.

Draw a diagram showing the path of rays through the telescope.

Compound Microscope.—A compound microscope consists of an objective which is a double convex lens of short focal length. The object PQ is placed at a distance slightly greater than its focal length. The objective forms an inverted and magnified image P'Q' of the object. This magnified image is viewed by the eye-piece. which is also a double convex lens of short but of comparatively larger focal length. The final image is P" Q".

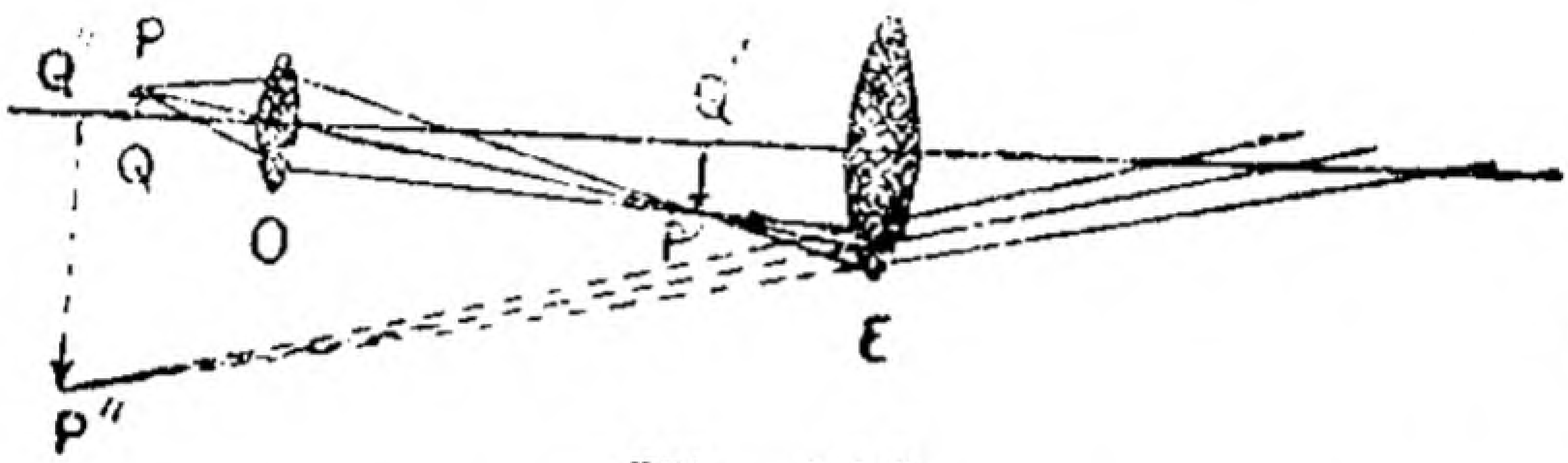


Fig. 119.

As the image formed by the objective is brought within the focus of the eye-piece, so a virtual, upright and magnified image is produced. As the image is highly magnified, so the object should be strongly illuminated. The microscope is fitted with the mirror which is plane on one side and convex on the other for the illumination of the object. For different kinds of work different sources of light are used. The total magnification produced is equal to $\left(\frac{g}{F}\right)\times\left(\frac{D}{f}\right)$ where $\frac{g}{F}$ is the primary magnification and $\frac{D}{f}$ is the magnification produced by the eye-piece. In the primary magnification g is the distance between the objective and the eye-piece and is called the *optical tube length* and F is the focal length of the objective. In the magnification produced by eye piece, f is the focal length of the eye-piece and D is the minimum distance of distinct vision which is equal to 25 cms.

Experiment 82.—**To set up the model of compound microscope.**

Apparatus.—A convex lens of focal length 3 cms. to serve as objective, a convex lens of focal length 6 cms. to serve as eye-piece, uprights, candle or electric lamp, wire gauze, a cardboard screen and a metre scale.

First method.—Find approximately the focal length of each lens. Take a paper and put some letter P on it, fix it in an upright and allow the print to receive light. Place the print between F and 2F of the short focus lens of focal length 3 cms. A real, inverted and magnified image of the object will be formed. By using the method of parallax, locate the image with the help of a needle. Place the second lens so that the needle comes within its focus when the eye is placed close to it. Remove the needle. You will be able to see a magnified image of the object.

Draw a diagram showing the path of rays through the lenses forming the compound microscope.

Second method.—Find approximately the focal length of each lens. Mount one of the lenses of short focal length in an upright and place a wiregauze CD illuminated by an electric lamp a little beyond the focus of the lens. Throw a magnified image C'D' of the gauze on a screen.

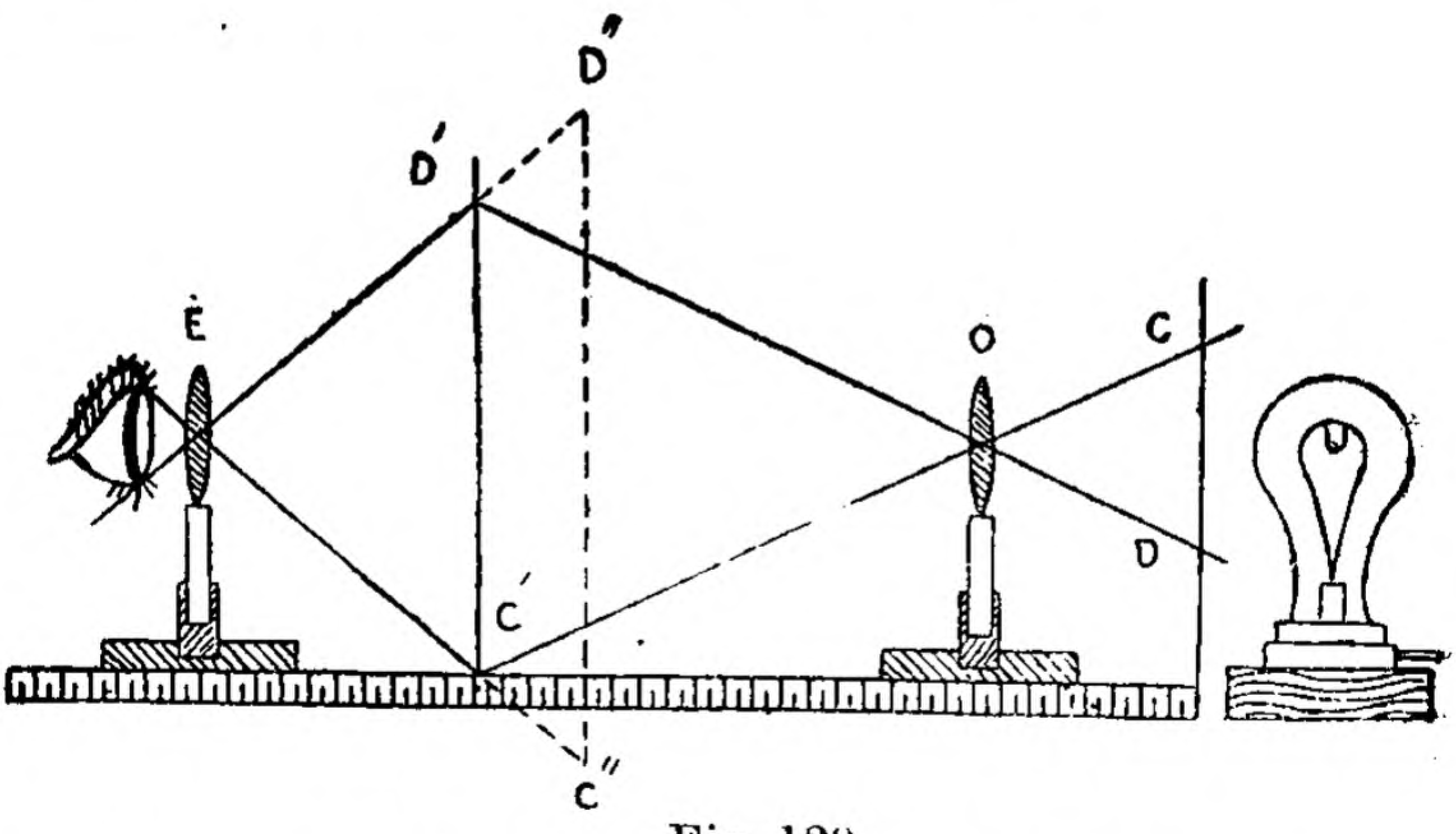


Fig. 120.

Mount the other lens on the other side of the screen at such a distance that the surface of the screen is seen distinctly when the eye is held close to the lens. Now remove the screen, and look through the lens. Move the eye-piece a little backwards and forwards till you see a distinct image of the illuminated wire gauze C''D''.

This combination of lenses represents a compound microscope.

MAGNETISM

GENERAL DIRECTIONS TO BE OBSERVED IN EXPERIMENTS ON MAGNETISM

(1) Do not allow a bunch of keys, a knife or pieces of iron to remain near the place where you are performing your experiments on magnetism.

(2) Do not demagnetise the magnets by allowing them to fall on the ground or on your working table. Use them carefully.

(3) When magnets are not to be used, these must be put back in the wooden box with their keepers on.

The N. pole of one magnet must be opposite to the S. pole of the other.

(4) Use a wooden stand for suspending a magnet. A retort stand will do very well.

(5) Use a hard drawing pencil for marking the lines of force and mark their direction with arrowheads.

(6) While plotting the magnetic field, fix the paper to the board with brass nails or wax.

(7) Do not disturb the position of the drawing board while plotting the magnetic field and marking the position of *neutral points.* Draw the boundary of the board with chalk so as to replace it in the same position in case it is disturbed.

(8) In experiments on *deflection magnetometer*, place the arms E and W for the *end-on position* and N and S for the *broadside-on position*. Do not be misled by the zero of the circular scale at the time of setting the magnetometer. In order to be sure that the magnetometer is set in the right position, remember that the axis of the deflecting magnet in both cases must be E and W.

(9) Tap the compass box of the deflection magnetometer, at the time of taking a reading. This makes the needle free if it was sticking before.

(10) There are various sources of error in deflection experiments and the method of eliminating them has been discussed fully in its proper place.

(11) In order to suspend a magnet, use unspun silk (*putt*). The trouble with threads of silk or cotton is that under the action of weight these begin to untwist, causing a magnet to turn round and round. In the case of a weak magnet, there is every likelihood of its resting in a direction other than the magnetic meridian. A suspension is free from twist when it has no tendency to turn one way or the other.

(12) A watch near a magnet is likely to be affected. It would, therefore, be better to keep it away from the influence of magnets.

CHAPTER XXVI

MAGNETIC FIELDS AND HOW TO PLOT THEM ; INVESTIGATION OF NEUTRAL POINTS

When a magnet is freely suspended, it points in a definite direction. The pole that points towards the north is the **N-seeking pole** of the magnet and the pole that points towards the south is its **S-seeking pole**. A magnet may be disturbed, but after making a few oscillations it comes to rest in the **magnetic meridian**.

Magnetic axis and magnetic equator.—The line joining the N-pole of the magnet to its S. pole is the **magnetic axis** of the magnet. But the straight line which is drawn perpendicular to the axis through its middle point is the **magnetic equator or neutral line.**

Fundamental law regarding attractions and repulsions.—The force of attraction or repulsion between two poles is directly proportional to the strength of the two poles and inversely proportional to the square of the distance between them.

$$F \propto \frac{m \times m'}{d^2} \text{ or } F = k\frac{m \times m'}{d^2} = \frac{1}{\mu} \cdot \frac{mm'}{d^2} \text{ (Coulomb's law)}$$

In this equation m and m' represent the two pole strengths, d the distance between them and k the constant of proportionality. μ is called the *permeability* of the medium which separates the two poles.

If the medium separating the poles be air, then $\mu = 1$ and $F = \frac{mm'}{d^2}$.

Unit pole. When two similar and equal poles one centimeter apart in air repel each other with a force of one dyne, each is a *unit pole.*

Suppose $m = m'$, $d = 1$ cm. and $F = 1$ dyne

Substituting these values in the formula $F = \frac{m \times m}{d^2}$,

we get $m^2=1$ or $m=\pm1$

We can express the strength of any other pole in terms of unit pole.

Magnetic field. The region round a magnet in which its influence is experienced is called *magnetic field.*

Strength of the field. The strength of the field at any point is the force experienced by a unit N-pole placed at that point.

The strength of the field is expressed in terms of a unit called a **gauss**. When a unit pole experiences a force of one dyne, the strength of the field is a *gauss*.

When we say that the field is of strength H, it means that a unit pole will experience a force of H dynes, and a pole of strength m will experience a force equal to m H dynes.

Lines of force. A *line of force* is a curve such that the tangent to it at any point represents the direction of the field at that point.

A *line of force* can also be defined as the path along which a unit N pole, if free, would move.

A magnetic field is represented by lines of force which can be traced either with a *compass needle* or with the help of *iron filings*.

Methods of mapping a magnetic field. As already mentioned, there are two ways of mapping a magnetic field. We can map a field with **compass needle** which is a short magnetic needle enclosed in a brass box, the top and bottom of which are made of glass. This method can be employed both in the case of strong as well as weak fields. But the second method of tracing the field with the help of iron filings can be used in the case of strong field only. The filings become magnets by induction and are arranged along the lines of force. We can get a permanent record of the magnetic field either by using photographer's P.O.P. paper or a paraffined paper.

Magnetic moment of a magnet. *It is the moment of the mechanical couple applied to a magnet in order to keep it perpendicular to the lines of force of a field of unit strength.*

It is generally denoted by the letter **M**. If the pole strength of a magnet be denoted by *m* and the distance between the two poles by *2l*, them $\mathbf{M = m \times 21}$.

Remember that the poles of a magnet are not at its ends, but a little distance away from the ends. The distance between the two poles is approximately $\frac{5}{6}$th of the length of the magnet and is known as the **magnetic length** of the magnet.

Earth's magnetic field. A magnetic needle which is freely suspended comes to rest in a definite direction under the action of the earth's field. Matters would be much simplified if we were to imagine a huge magnet buried in earth with its poles near the geographical poles and with its S. pole in the northern hemisphere and its N. pole in the southern hemisphere. The field due to the earth over a certain region may be considered to be **uniform**. *A uniform field is one in which the magnitude and direction of force at every point is the same.* It is represented by parallel lines of force. The field due to a magnet is **non-uniform** because it is very strong near the magnet and weak at other places. The following figure show a *uniform field* due to the earth, and a *non-uniform* field due to a magnet.

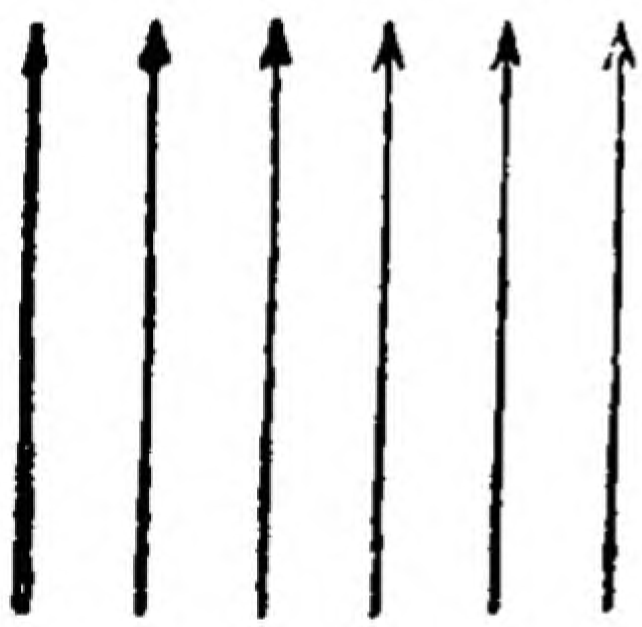


Fig. 121. *a*
Uniform Field.

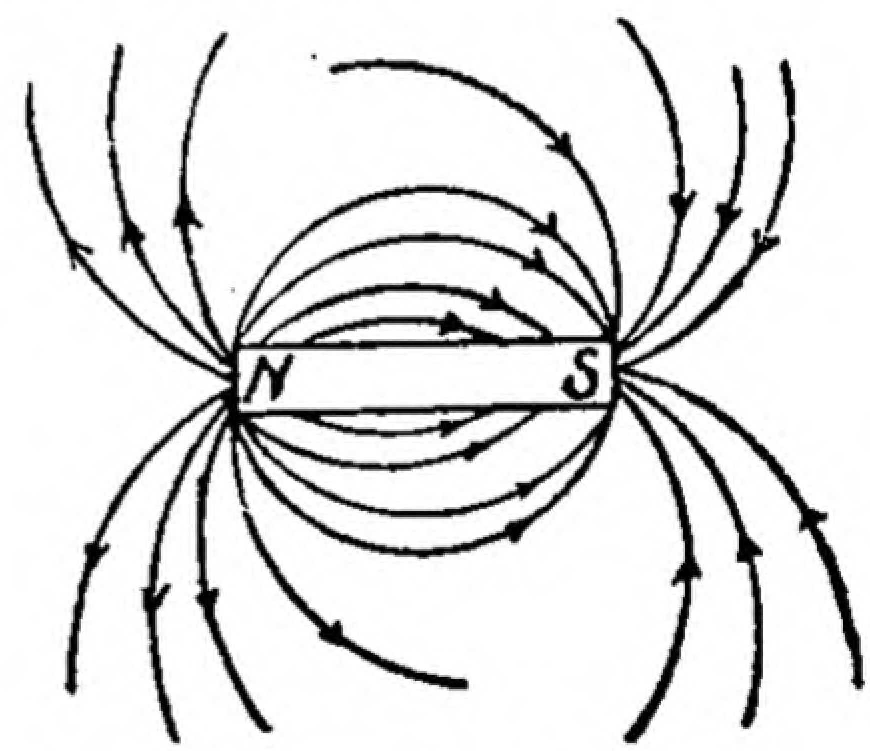


Fig. 121. *b*
Non-uniform Field to a magnet.

The earth's field can be resolved into two components, horizontal and vertical. The horizontal component of the earth's field is denoted by H and our apparatus are so designed as to be operated only by horizontal compenent. The vertical component is neutralised by the reaction of pivots.

Neutral Points.—When we plot a field due to a magnet, we really map a resultant field compounded of earth's field and the field due to the magnet. In the vicinity of the magnet, its field predominates. There are certain places where the two fields are equal and opposite. These are **neutral regions**. A compass needle will cease to oscillate or that its movements will become very slow in such a region. If this region be very much narrowed, the centre of the region is the **neutral point**. It is avoided by lines of force. A neutral point is that where the field of the magnet is balanced exactly by the field due to the earth. It is a point of zero intensity. We can find a neutral point roughly with the help of the tracing compass. When it is moved about the magnet in the sphere of its influence, we come across certain points where there is no certainty about the direction of N. pole. Such points are neutral points. These points are useful in determining the pole strength and the magnetic moment of a magnet. We shall explain later on how to determine these quantities.

"End-on position" of the magnet.—A magnet is said to be in the *"end on" position* with respect to a point when it is on the axis of the magnet produced.

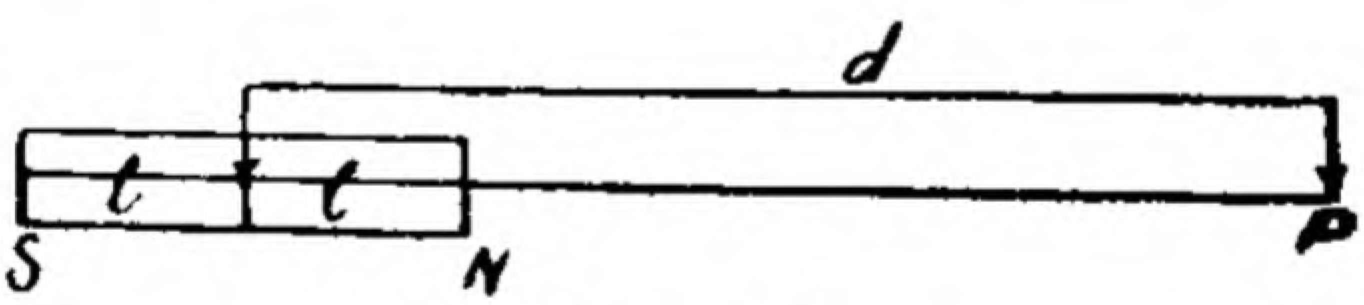


Fig. 122.

The magnet is in the "end-on" position with respect to the point P whose distance from the centre of the magnet is d and the length of the magnet $2l$. Let m denote the pole strength of the magnet.

The resultant force at P due to the poles of the magnet is equal to

$$\frac{m}{(d-l)^2}-\frac{m}{(d+l)^2}=\frac{2\times 2mdl}{(d^2-l^2)^2}=\frac{2\text{ M }d}{(d^2-l^2)^2},$$

where M is the magnetic moment of the magnet.

This is the accurate formula which should be used for determining the force in the "end-on" position.

But when the distance d is large as compared to the length of the magnet, the above formula is reduced to $2M/d^3$.

"Broard-side on" position of the magnet. A magent is said to be in the "broadside-on" position with respect to a point when it is on the magnetic equator.

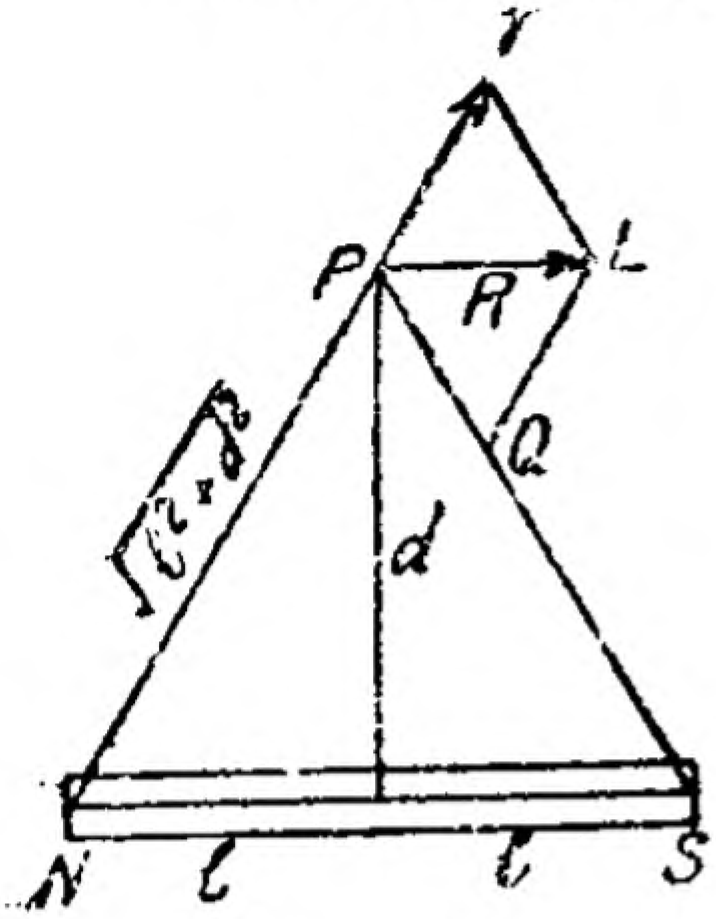


Fig. 123.

In the diagram the magnet is in the 'broadside-on' position with respect to the point P.

Let $2l$ be the length of the magnet, m its pole strength and d the distance of the point P from the middle point of the magnetic axis.

The force at P due to $N=\frac{m}{(d^2+l^2)}$. It is a force of repulsion. Let it be represented by PT.

The force at P, due to $S=\frac{m}{(d^2+l^2)}$. It is a force of attraction. Let it be represented by PQ.

Since the two forces are equal, therefore, PQ=PT.

In order to determine the resultant force, draw the parallelogram on the lines PT and PQ. The diagonal PL represents the resultant force.

$\because$ $\triangle$s PLQ and PNS are similar.

$\therefore \frac{PL}{PQ}=\frac{NS}{PS}$ [PL being the exterior bisector of the angle NPS is parallel to NS.

$$\text{Or}\quad PL=PQ\times\frac{NS}{PS}=\frac{m}{(d^2+l^2)}\times\frac{2l}{\sqrt{d^2+l^2}}=\frac{2ml}{(d^2+l^2)^{\frac{3}{2}}}$$

$=\frac{M}{(d^2+l^2)^{\frac{3}{2}}}$ where M is the magnetic moment of the magnet.

This is the accurate formula for determining the force in the "broadside-on" position. But when the distance d is large as compared to the length of the magnet, the formula is reduced to $\frac{M}{d^3}$.

Position of a magnet and neutral points :—

(1) When a magnet is placed along the magnetic meridian with its N-pole towards the south, the two neutral points obtained are on its axis produced.

Since at a neutral point the fields due to the earth and the magnet are equal and opposite, therefore, $H = \frac{2Md}{(d^2-l^2)^2}$ where H is the strength of the earth's field, which is equal to ·329 C. G. S. units and $\frac{2Md}{(d^2-l^2)^2}$ is the field due to the magnet, when it is in the 'end on' position. Thus we can calculate the *magnetic moment* of the magnet, and knowing the magnetic moment we can find the *pole strength.*

(2) When the magnet is placed along the magnetic meridian with its N-pole towards the north, the neutral points are obtained on the equatorial line.

Since at a neutral point the two fields are equal and opposite, therefore $H = \frac{M}{(d^2+l^2)^{\frac{3}{2}}}$.

The value of H being known, M can be calculated. Knowing M, the *pole strength m* can be calculated.

(3) In any other position of the magnet, the pole strength of the magnet is calculated by the application of the law of triangle of forces. Hence the magnetic moment of the magnet is easily determined.

Experiment 83.—**To map out the earth's field with a tracing compass needle.**

Apparatus.—Tracing compass, drawing board, a sheet of paper, brass nails, a small magnet, and a metre-scale.

Method.—In the first place, remove all magnets and iron pieces away from the place where an experiment on the mapping of a magnetic field is to be performed. Fix a paper on the drawing board by using brass nails. Place the tracing compass near the lower edge of the paper, and rotate the board so that the magnetic needle becomes parallel to the side BC of the paper as shown in figure 124. Mark dots against the ends of the tracing compass. Remember that the board is rotated as so to make the

needle parallel to the side BC of the paper for the sake of convenience only. Now slide the compass forward so that the S. pole coincides with the second dot that was marked against the N. pole and again mark a third dot against

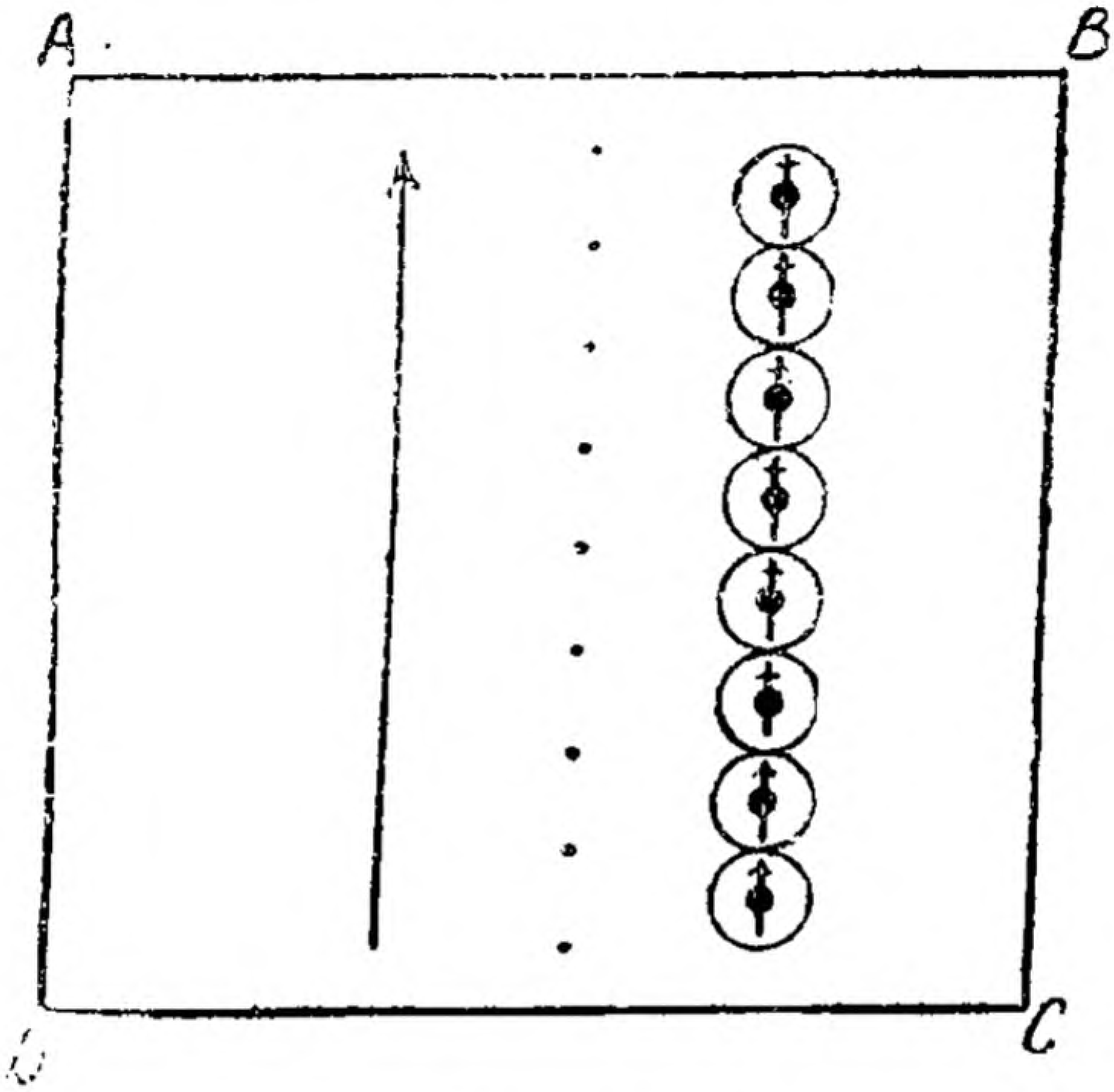


Fig. 124.

the N. pole of the needle. Move the compass in the forward direction so that the S. pole of the needle coincides with the third dot and mark a fourth dot against the N. pole. Go on sliding the needle step by step and marking by dots the position of the N. pole of the needle at every stage, till the edge of the paper is reached. Join the different points. Now place the needle at a distance of $\frac{1}{2}$ cm., from the first position and again mark a number of dots as explained above. Repeat it four or five times. Join the points along different lines. Mark the direction of the lines by arrow-heads. You will find that all the lines will be parallel and have the same direction. The positive direction of the lines of force is from the south towards the north. The earth's field is uniform. A uniform field can be represented by parallel lines only.

Precautions.—1. In such experiments use a hard drawing pencil which is well chisled.

2. Bunch of keys, knives, pieces of iron, etc. must be kept away from the place where such experiments are to be tried.

3. The direction of the lines of force must be shown.

4. See that the tracing compass is in working order.

5. The different points should be joined by free hand drawing.

Experiment 84.—**To map the magnetic field by placing the magnet along the magnetic meridian with** (*i*) **N. pole towards south ;** (*ii*) **N. pole towards north and to calculate the Pole strength and magnetic moment of the magnet with the help of neutral points.**

Apparatus.—Drawing board, a sheet of paper, brass nails, a magnet 3″ long, tracing compass.

(1) *Magnet along the magnetic meridian with N. pole towards south.*

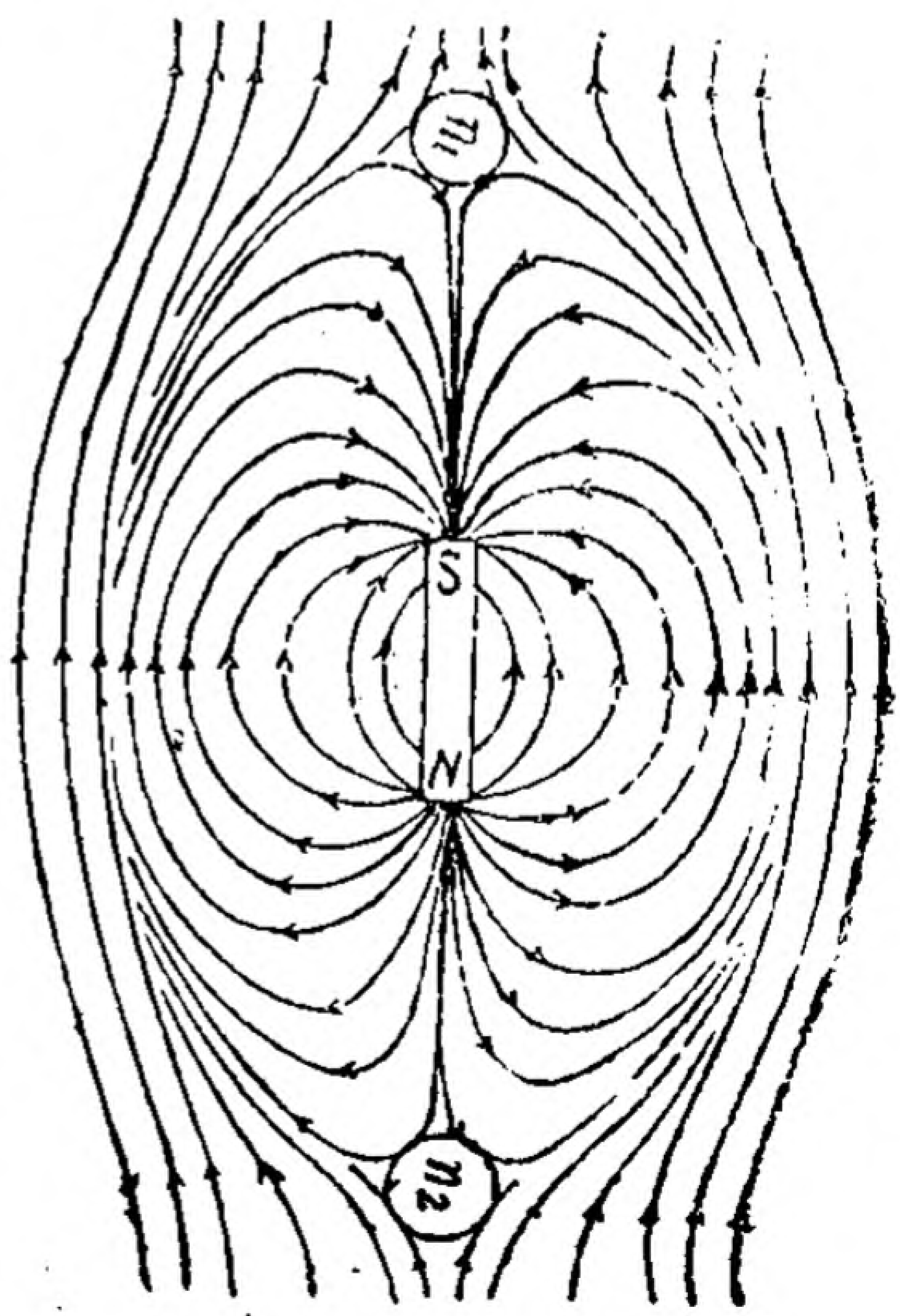


Fig. 125.

Method. - Fix a sheet of paper on the drawing board with brass nails or wax. In order to trace the magnetic meridian, keep all magnetic substances away. Place a compass somewhere near the bottom of the middle of the sheet of paper. Rotate the drawing board till the needle is parallel to the edge of the paper. Mark dots against the poles of the needle. Slide the compass forward till the S. pole coincides with second dot and mark a third dot against the N. pole. Mark a few points in this way and join them by a line. It will represent the earth's field. Place the edge of magnet along this line and trace its boundary and mark the positions of north

and south poles. The position of the neutral points should be estimated with the help of the compass needle so that they lie on the paper, before actually tracing the lines of force. At the neutral point the needle will point in any direction and behave as though it were "dead." With the help of a piece of chalk trace the boundary of the drawing board and see that you do not disturb the board while plotting the field and neutral points. Trace the field with the help of compass. Take a number of points along the is des and ends of the magnet and place the compass so that its S. pole lies on one of these points near the N. pole of the bar magnet and mark a dot against the other end of the compass. Move the compass forward so that the S. pole coincides with the previous dot and again make a mark against the N. end. Go on doing it till the other end of the magnet or the edge of the paper is reached. Mark in this way as many lines as possible. Mark arrows along the lines. Trace lines on both sides of the magnet. In order to mark the position of the neutral points find places where the oscillations of the needle become slow or cease. Mark the field about these places. A kind of *curvilinear quadrilateral* will be obtained. Make this quadrilateral as narrow as possible and then by placing the compass within the neutral region draw a circle round it. In the case under consideration there are two neutral points n_1 and n_2 along the magnetic axis.

In order to determine the magnetic moment of the magnet, measure the distance between the two neutral points and half of this distance is equal to d cms. Let $2l$ denote the distance between two poles. At a neutral point the field of the earth is equal and opposite to the field due to to the magnet.

Hence $H=\frac{2Md}{(d^2-l^2)^2}$. The value of H is ·329 C. G. S. units. Calculate the magnetic moment M of the magnet.

Since $M=m\times 21$ where m is pole strength, and $2l$ the distance between the two poles, calculate the pole strength of the magnet.

Record your observations as follows:—

$H=\cdot 329$ Gauss.

Distance of n_1 from the middle of magnet	Distance of n_2 from the middle of magnet	Mean distance (d)	Distance between two poles ($2l$)	Magnetic moment (M)	Pole strength (m)

(2) ***Magnet** along the magnetic meridian with N. pole towards the north*. In this case also, draw a line representing the earth's field (magnetic meridian) as explained before. Place the magnet along this line with its N. Pole towards the north and trace its boundary and mark the positions of the poles.

With the help of the tracing compass trace the field and

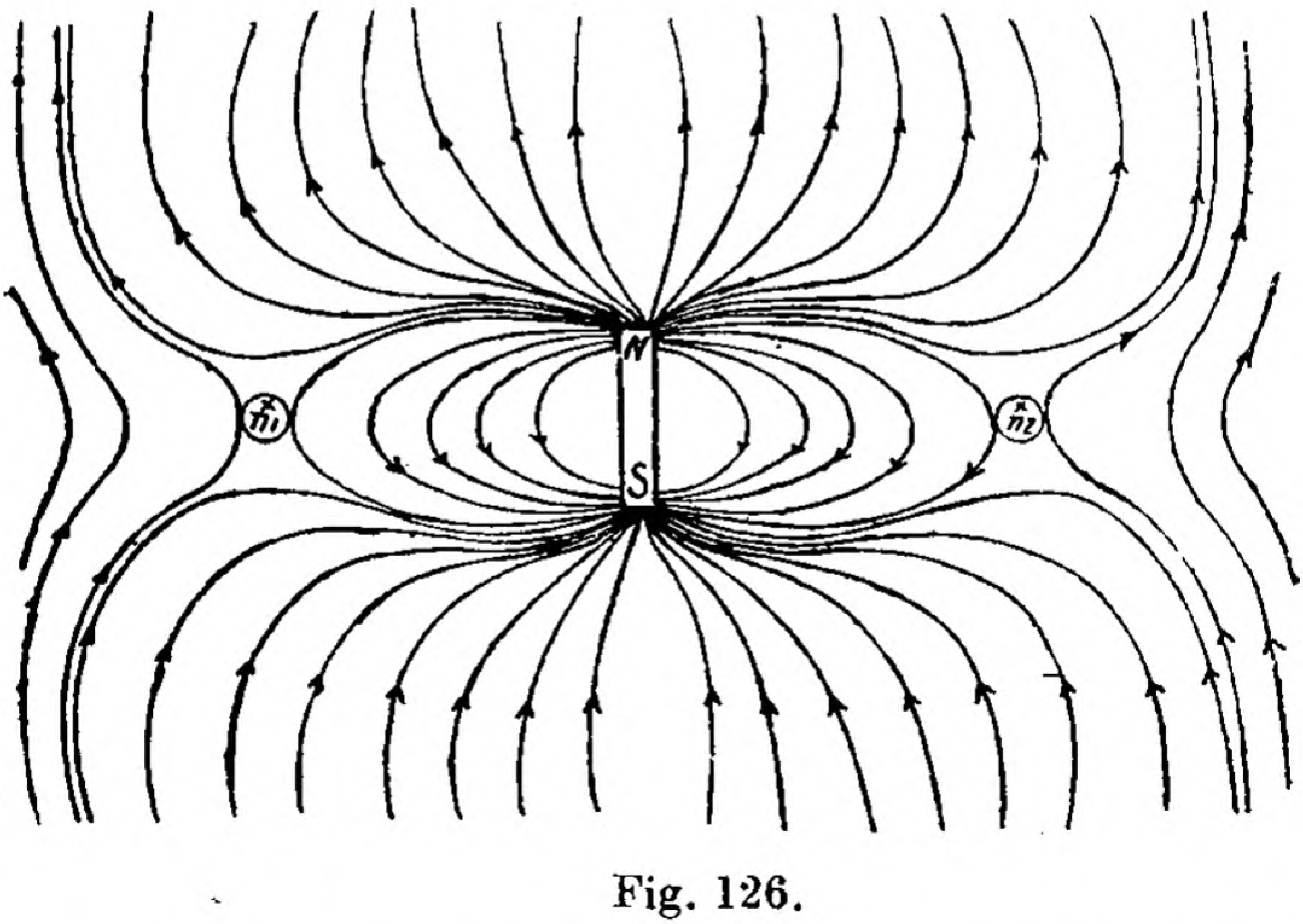


Fig. 126.

neutral points on both sides of the magnet as explained before. The neutral points n_1 and n_2 will be on the equatorial line east and west of the magnet.

Measure the distance of each neutral point from the poles of the magnet. Let these distances be denoted by x_1, x_2, x_3 and x_4 respectively and their mean by x.

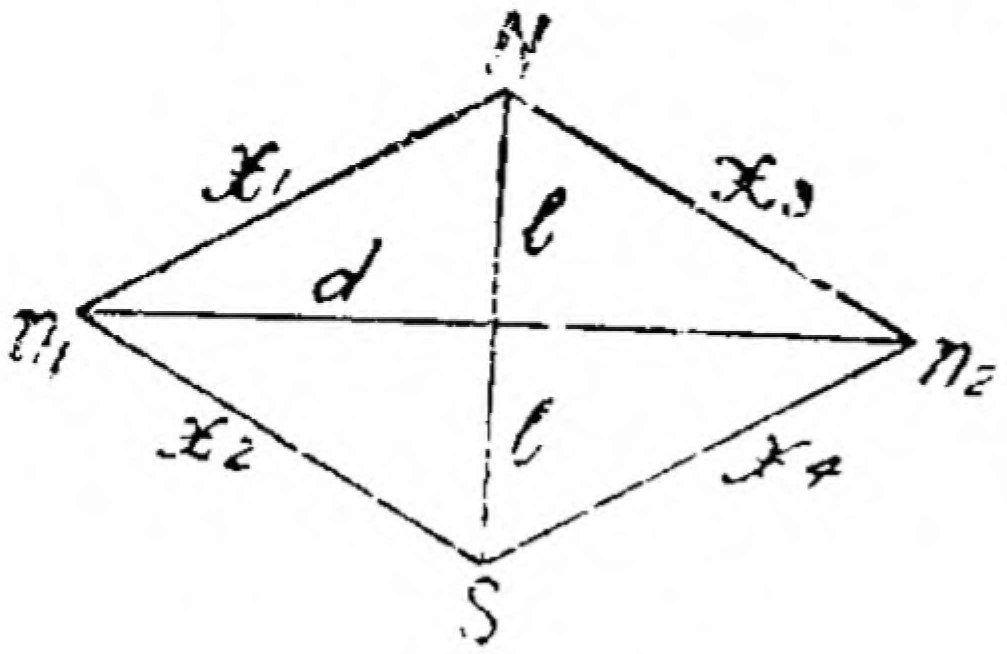


Fig. 127.

$x=\sqrt{d^2+l^2}$

$$H=\frac{M}{(d^2+l^2)^{\frac{3}{2}}}=\frac{M}{x^3}.$$

Thus M can be calculated and from it the pole strength m can be calculated from the relation $M=m\times 2l$.

Record your observations as follows :—

H=·329 Gauss

Distance x_1	Distance x_2	Distance x_3	Distance x_4	Mean distance x	Magnetic moment $M=Hx^3$	Pole strength (m)

Precautions.—1. While plotting neutral points, do not disturb the position of the board. Draw out its boundary with a piece of chalk, and this would enable you to recover the position in case the board is disturbed.

2. When trying to investigate the position of neutral points, there is no need of tracing the whole of the field. It is always helpful to get an idea of their position with the help of the tracing compass. The places where the oscillations of the needle cease and there is no certainty about the direction of the N. Pole, are neutral regions. Plot the field round these regions and thus find the neutral points without much waste of time.

3. Mark by arrows the direction of the lines of force.

4. Mark both the neutral points.

5. Lines of force should not cross each other.

Experiment 85.—**To map the field by placing the magnet inclined at an angle of 60° to the magnetic meridian and to find the magnetic moment and the pole strength of the magnet from the position of the neutral points.**

Apparatus.—Drawing board, a sheet of paper, brass nails, a magnet 3″ long, tracing compass, metre-scale, set squares, protractor.

Method.—Fix sheet of paper on the drawing board by means of pins or wax and trace the boundary of the board with a piece of chalk. Near the middle of the paper mark the direction of the earth's field with the help of compass.

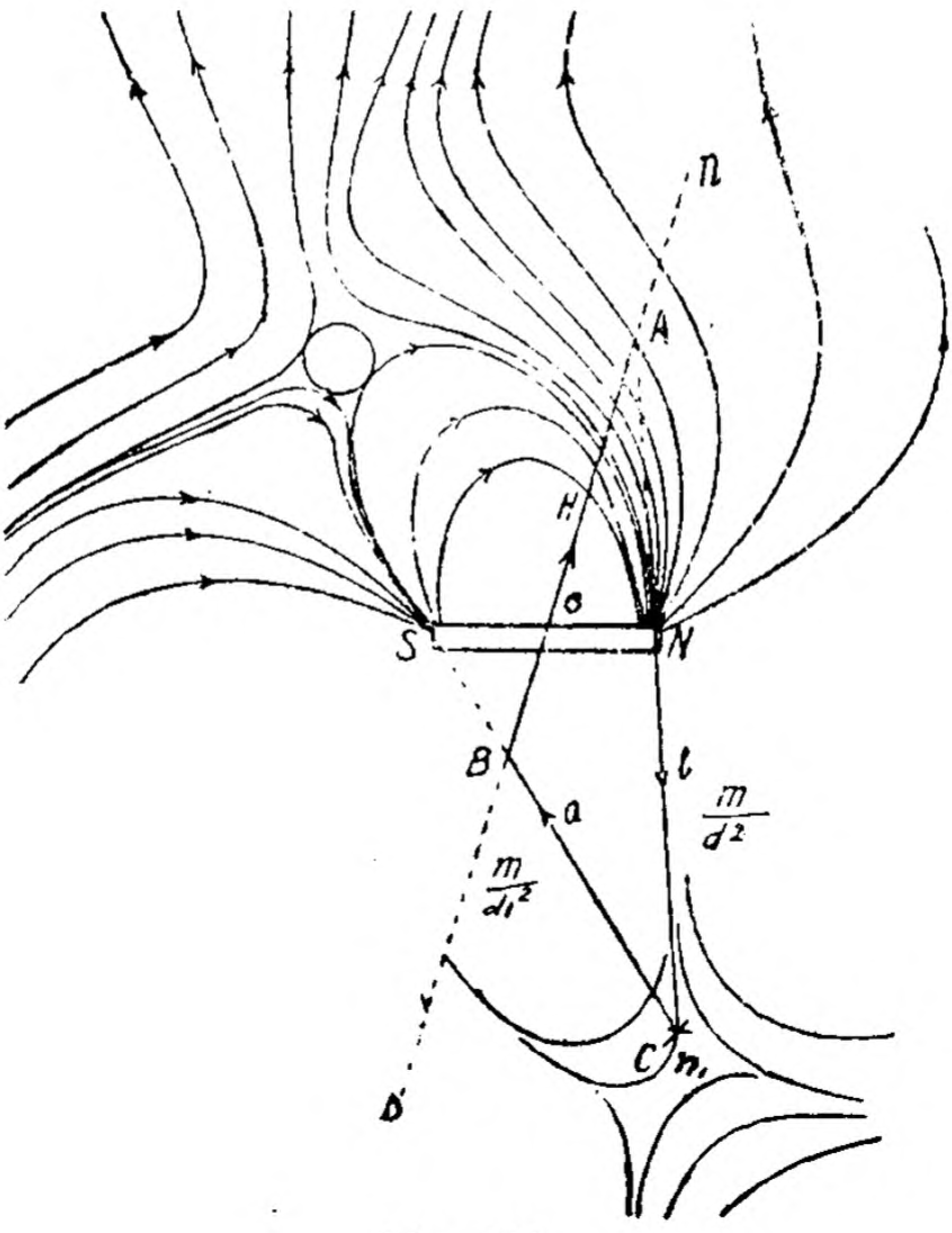


Fig. 128.

Draw a line making an angle of 60° with it. Place the magnet along this line. Trace the boundary of the magnet with a hard drawing pencil. With the help of compass trace the field and find the position of the neutral points as accurately as you can. Figure shows such a map with two neutral points.

Let us see next how to calculate the pole strength from the knowledge of the neutral points. Join the neutral point n_1 to the poles of the magnet, as shown in the figure. Produce the line joining the neutral point to the N. pole of the magnet so as to meet the earth's line of force in the point A. Thus the triangle ABC is formed whose sides are denoted by a, b and c respectively. Measure these sides carefully. Being a triangle of forces, the sides of the triangle represent the different forces. The side a represents the force m/d_1^2 where d_1 is the distance of the neutral point from the S. pole of the magnet ; the side b represents the force m/d^2 where d is the distance of the neutral point from the N. pole of the magnet. The force H is represented by c, the third side of the triangle.

Thus we have $a : b\ c :: \frac{m}{d_1^2} : \frac{m}{d^2} : \mathrm{H}$

Or $\frac{a}{\frac{m}{d_1^2}} = \frac{b}{\frac{m}{d^2}} = \frac{c}{\mathrm{H}}$.

Since $\frac{a}{\frac{m}{d_1^2}} = \frac{c}{\mathrm{H}}$ or $\frac{ad_1^2}{m} = \frac{c}{\mathrm{H}}$.

$\therefore\ m = \mathrm{H} \times d_1^2 \times \frac{a}{c} = \cdot 329 \times d_1^2 \times \frac{a}{c}$.

Smilarly $m = \mathrm{H} \times d^2 \times \frac{b}{c} = \cdot 329 \times d^2 \times \frac{b}{c}$.

Find the mean of the two values of m.

Calculate the two values of m from the second neutral point.

Calculate the magnetic moment M of the magnet from the relation $\mathrm{M} = m \times 2l$.

Record your observations thus :

Distance of the neutral point from the poles	Sides of the triangle			Pole Strength m	Magnetic moment M
	a	b	c		
1st point d—— d_1——				mean	
2nd point d—— d_1——				mean	

Experiment 86.—**To map the field of the magnet with the help of iron filings.**

Apparatus.—Bar magnets, iron filings, a thin sheet of glass, a sieve for sprinkling iron filings, and a paraffined paper.

Method.—Place a sheet of thin glass on a magnet or magnets and on the sheet of glass place a paraffined paper. With the help of a sieve sprinkle iron filings uniformly over the paper. Tap the paper gently, so as to give freedom of movement to the filings, which will arrange themselves along the lines of force. By this method strong fields can be mapped ; therefore lines of force in the immediate neighbourhood of the magnet are well exhibited. Now take a burner and pass it lightly over the paper, so as to melt the

wax and then allow it to cool. The filings will be embedded in the wax. Wax could also be melted by means of a jet of steam. Thus a permanent record is obtained.

A permanent record of the field can also de obtained by using a photographer's P. O. P. paper. The filings are sprinkled on the paper and then it is exposed to sunlight. Thus impressions are made on the paper.

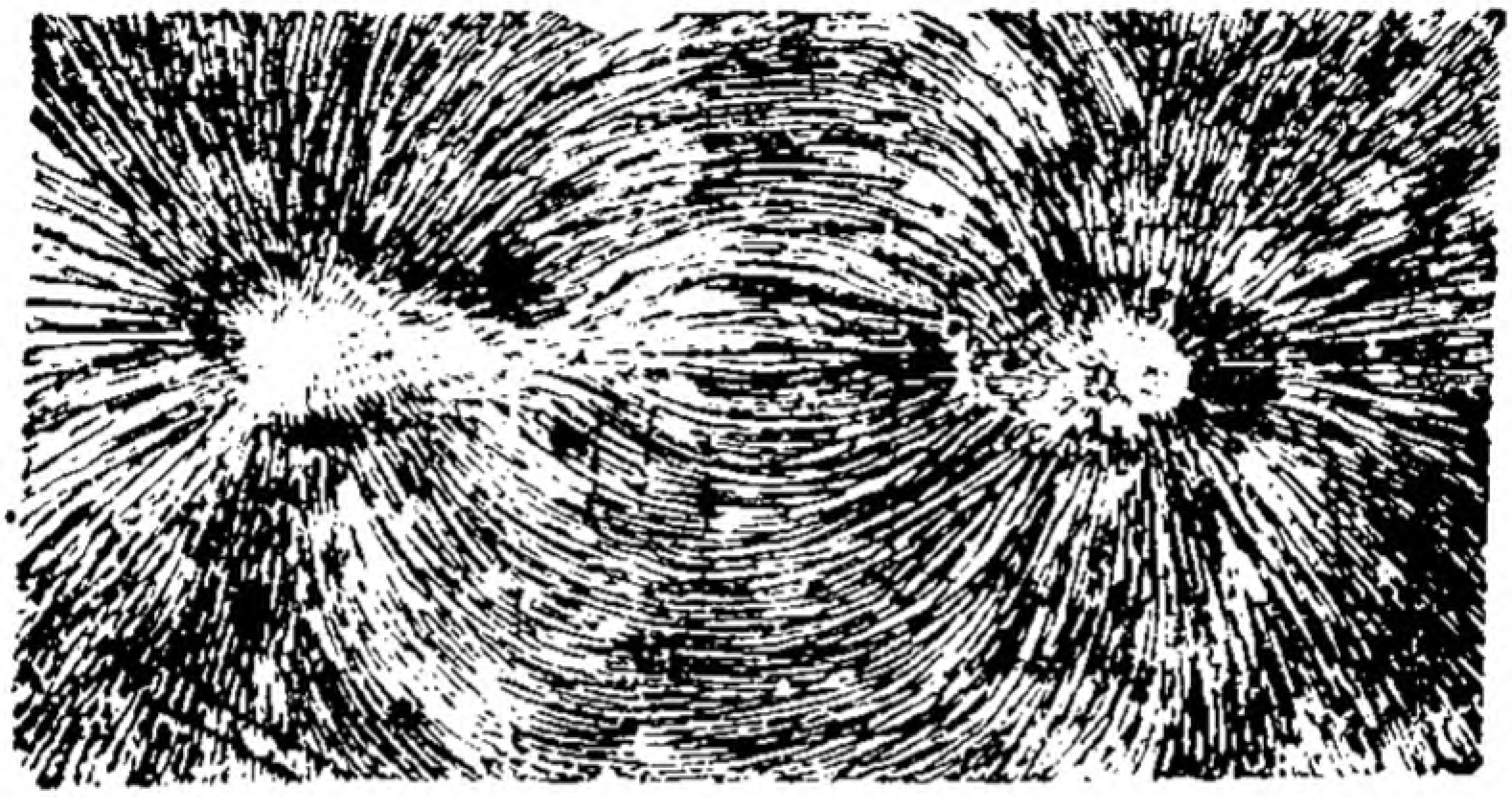


Fig. 129.

The filings are then removed and the image is fixed by treating the P. O. P. paper with chemicals.

Fig. 129 shows the general arrangement of the lines of force over a bar magnet. The lines of force are supposed to run from N. pole to S. pole.

Exercises

(1) Place two magnets parallel to each other with their N. poles pointing to the north at a distance apart equal to 4 cms. Map out the magnetic field by using a tracing compass.

(2) Trace the lines of force of a horse-shoe magnet by using iron filings.

(3) Place a magnet in the east-west position with the S. pole towards the east. Plot the field and mark the position of the neutral points. Calculate the pole strength of the magnet from the neutral points.

CHAPTER XXVII

MAGNETOMETER : COMPARISON OF MAGNETIC MOMENTS OF MAGNETS, ETC.

Tangent law.—If there be two fields at right angles to one another, the direction of the resultant force is obtained by the *law of parallelogram of forces*. In the figure there are two magnetic fields **F** and **H** acting at right angles to one another, the resultant force is represented by **R**

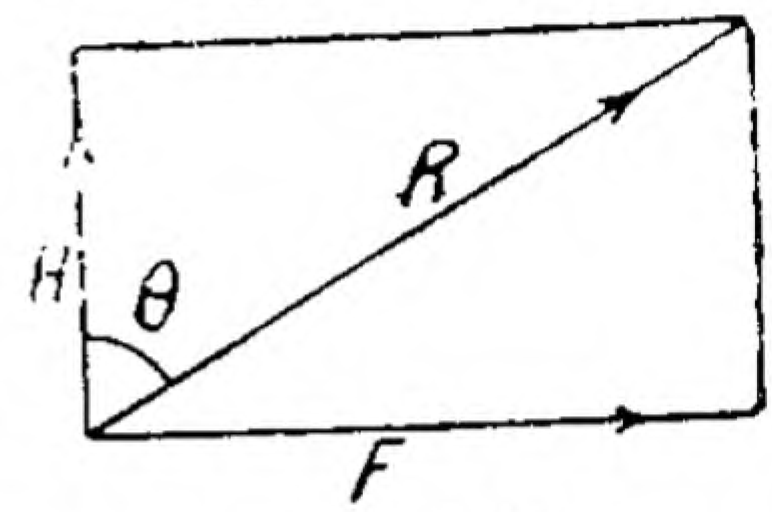


Fig. 130.

If R makes an angle θ with the field H, then $\frac{F}{H} = \tan\theta$ or $F = H\tan\theta$. In actual practice, the field H is due to earth and is called the *controlling field* and the field F is due to the magnet and is called the *deflecting field*.

Hence we have $\frac{\text{Deflecting field}}{\text{Controlling field}}$ =Tangent ef the angle of deflection.

The deflecting field can also be produced by means of an electric current. In the ***tangent galvanometer*** when the needle is deflected out of the magnetic meridian, we can apply the tangent law $F = H\tan\theta$. The value of F being known, the current C can be calculated by noting the deflection produced.

Magnetometer.—It is an instrument by means of which we can compare the magnetic moments of two magnets. It consists of a compass box which contains a small magnetic needle pivoted at the centre and is free to move in a horizontal plane. A long aluminium pointer is attached at right angles to the needle which moves over the circular scale graduated in degrees. Below the scale is a plane mirror which helps us to take readings without the error of parallax. At the time of reading the deflection, see that the pointer hides its own image. On both sides of the compass box are two arms which carry scales graduated in millime-

ers. The zeros of the scales coincide with the centre of the circular scale, where the needle is pivoted.

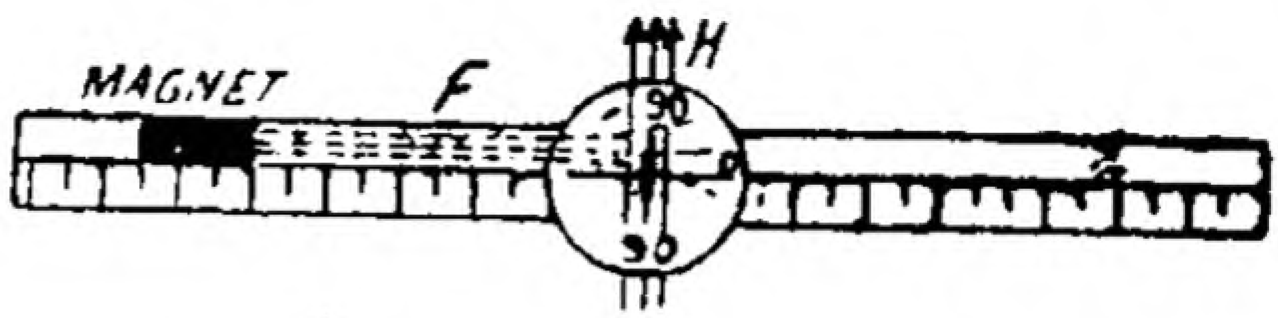


Fig. 131.

Adjustment of the magnetometer. There are two positions that we have to take into consideration :

(*i*) *the "end on" (or Tan A) position.*

(*ii*) *the "broadside on" (or Tan B) position.*

"**End-on**" **position.**—In order to adjust the magnetometer for the end-on position, rotate the instrument till the arms point to the E and W position, or *that the pointer becomes parallel to the arms.* The axis of the magnet placed in one of the arms of the magnetometer with the object of producing the deflecting field is east and west. In this position the controlling field H due to the earth is perpendicular to the deflecting field F due to the magnet. See Fig. 131.

"**Broadside on**" **position**. In order to adjust the magnetometer for the "broadside-on" position, rotate the instrument till the arms point to the N and S position. The position of the deflecting magnet as shown in Fig. 132 is such that its axis points east and west. Again in this position the two fields, *viz.*, the controlling field (H) and the deflecting field (F) are at right angles. The tanget law is again applicable.

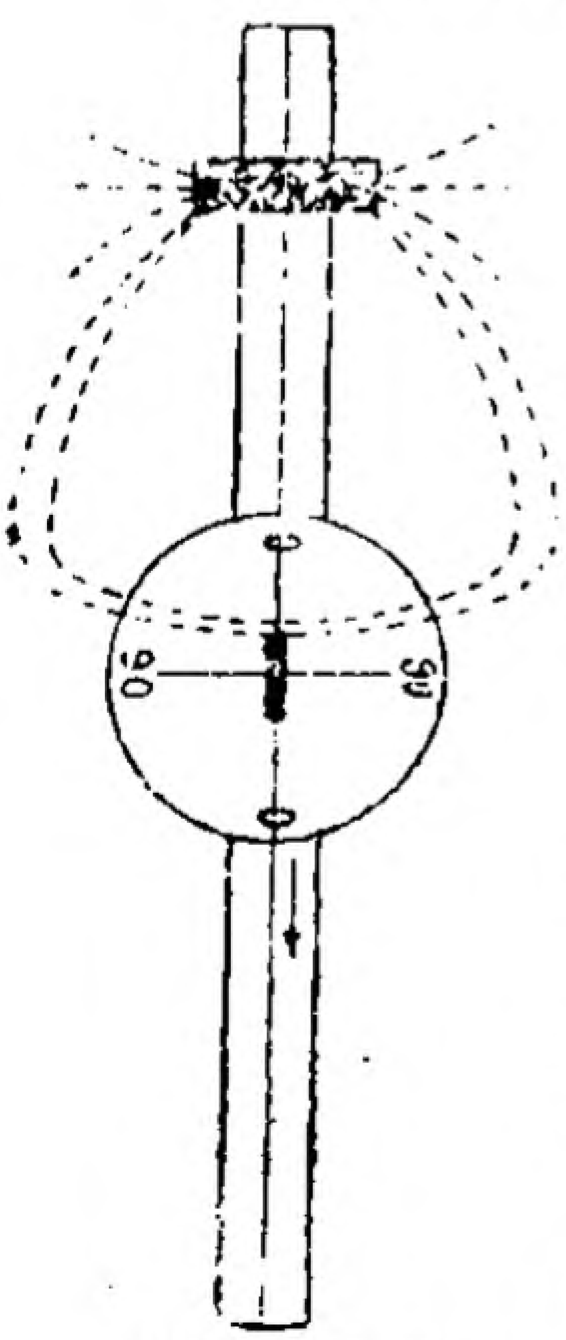


Fig. 132.

In order to be sure that the magnetometer has been set in the right position—end-on or "broadside-on", remember that *the axis of the deflecting magnet in both cases must point east and west.*

The "end-on" position is preferred to the broadside-on position, since we get a large deflection for the same distance.

Magnetometer with four arms.

Fig. 133. shows a magnetometer with four arms, two of which point to east and west, and the other two to north and south.

Out of the two pairs of graduated arms, when one of the pairs is adjusted for the "end-on" position, the magnetometer is adjusted for the broad-side-on position automatically or *vice versa*.

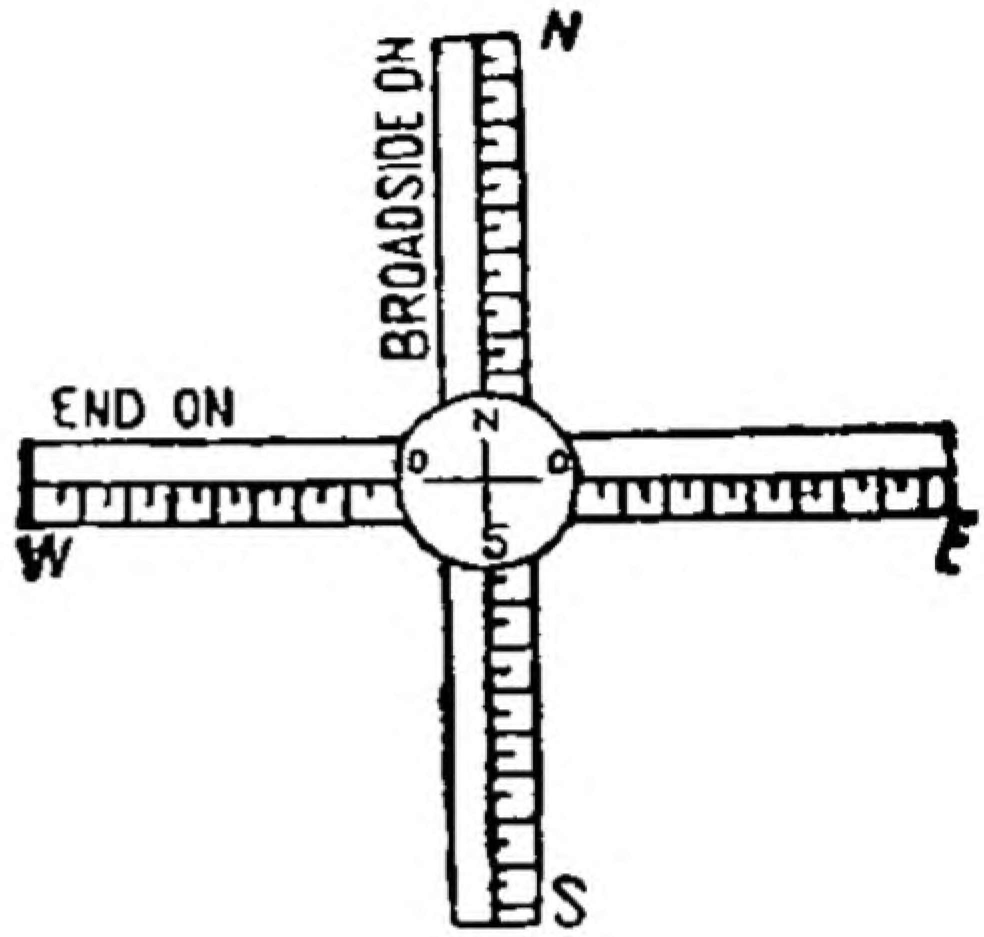


Fig. 133.

Errors in deflection experiments and their correction.

(*a*) **The needle may not be pivoted at the centre of the circular scale.** This source of error is eliminated by reading both ends of the pointer. One end reads too high and the other too low. The mean of the two readings is the correct one.

(*b*) **The magnet may be irregularly magnetised.** This error is eliminated by reversing the magnet end for end.

By taking readings in this way, the error caused by the pointer being not perpendicular to the magnetic needle is also eliminated.

(*c*) **The pivot may not be at the zero of the millimeter scales.** Readings should be taken by placing the magnet at an equal distance in the other arm of the magnetometer.

By observing the precautions mentioned above, the error caused by the arms not being exactly towards east and west is also removed. At the time of taking a reading, tap the compass box gently so as to be sure that the pointer is free to move.

Experiment 87.—**To compare the magnetic moments of two magnets by the** (*i*) *deflection method* (*ii*) *null method* **by placing the magnetometer in the** *'end-on' position.*

Apparatus.—Magnetometer, two magnets, set squares and a metre-scale.

(*i*) **Deflection method.**

Method. Adjust the magnetometer for the "end-on" position as explained above *i.e.*, rotate the frame till the arms point east and west. In this position the pointer and not the magnetic needle will be parallel to the arms. Use

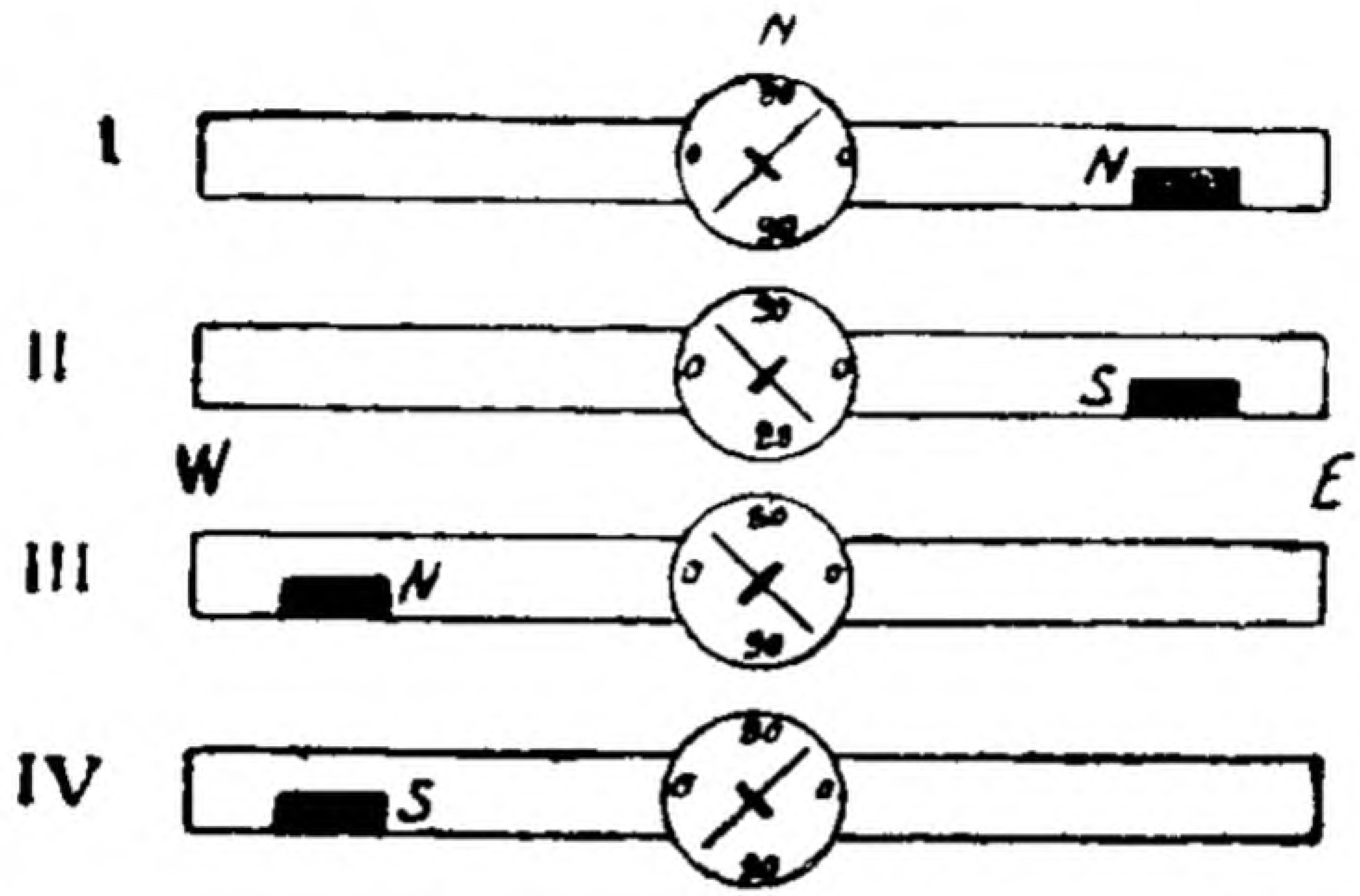


Fig. 134.

a half meter stick and a set square to bring the arms as exactly as possible to the east and west direction. Mark the middle point of the magnets with a piece of chalk and call one of the magnets as A and the other B. It is better to mark the boundary of the instrument with a piece of chalk so that in case it is disturbed it can be replaced in its original position.

Place the magnet A in the east arm of the instrument with the N. pole facing the needle. Read both ends of the pointer (Position I, Fig. 134). Reverse the magnet and note deflection again (Position II, Fig. 134). Now place the magnet A on the west arm of the instrument at the same distance with N. pole facing the needle. Read both ends of the pointer (Position III, Fig. 134). Reverse the magnet, and read both ends of the pointer (Position IV, Fig. 134).

The mean of eight readings is the correct angle of deflection.

Let the mean deflection be denoted by θ_1 and the magnetic moment of the magnet A by M_1.

Repeat your observations with the second magnet B by placing it at the same distance d which is measured from the middle of the magnet to the centre of this needle. Let the mean of eight observations in this case be denoted by θ_2 and the magnetic moment of the magnet B by M_2.

$\frac{M_1}{M_2}=\frac{(d^2-l_1^2)^2}{(d^2-l_2^2)^2}\times\frac{\tan\theta_1}{\tan\theta_2}$ where $2l_1$ stands for the length of the first magnet and $2l_2$ for the length of the second magnet.

$\frac{M_1}{M_2}=\frac{\tan\theta_1}{\tan\theta_2}$ if l is small as compared to d.

Theory. The controlling field of the earth **H** is at right angles to the deflecting field F due to the magnet. The tangent law becomes applicable. If θ_1 were to denote the angle of deflection with magnet A, $F=H\tan\theta_1$.

But $$F=\frac{2M_1d}{(d^2-l_1^2)^2}$$

$\therefore$ $$H\tan\theta_1=\frac{2M_1d}{(d^2-l_1^2)^2}$$

Similarly $$H\tan\theta_2=\frac{2M_2d}{(d^2-l_2^2)^2}$$

$\therefore$ $$\frac{M_1}{M_2}=\frac{(d^2-l_1^2)^2}{(d^2-l_2^2)^2}\times\frac{\tan\theta_1}{\tan\theta_2}$$

If l is negligibly small as compared with d, then

$$\frac{2M_1}{d^3}=H\tan\theta_1$$

Similarly $$\frac{2M_2}{d^3}=H\tan\theta_2$$

Or, $$\frac{M_1}{M_2}=\frac{\tan\theta_1}{\tan\theta_2}$$

Enter your observations thus :

Length of magnet A, $2l_1=$

Length of magnet B, $2l_2=$

Magnets	Distance	Deflection with Magnet in E—arm		Deflection with Magnet in W—arm		Mean deflection	$\frac{\tan\theta_1}{\tan\theta_2}$
		N. pole facing the needle	S. pole facing the needle	N. pole facing the needle	S. pole facing the needle		
Magnet A	50 cms.	1.——	3.——	5.——	7.——	θ_1	
		2.——	4.——	6.——	8.——		
Magnet B	50 cms.	1.——	3.——	5.——	7.——	θ_2	
		2.——	4.——	6.——	8.——		

Repeat the observation by changing the distance though keeping it the same for the two magnets A and B. If the magnets are short and d is large as compared to the length of the magnet, then

$$\frac{M_1}{M_2}=\frac{\tan\theta_1}{\tan\theta_2}.$$

Calculations

Correct formula being used.

$$\frac{M_1}{M_2}=\frac{(d^2-l_1^2)^2}{(d^2-l_2^2)^2}\times\frac{\tan\theta_1}{\tan\theta_2}.$$

Taking logarithm of the right hand expression we have

$2[\log(d^2-l_1^2)-\log(d^2-l_2^2)]+(\log\tan\theta_1-\log\tan\theta_2)$.

Suppose that

$$d=50{\cdot}0 \text{ cms.}$$
$$2l_1=14{\cdot}0 \text{ cms.}$$
$$2l_2=16{\cdot}0 \text{ cms.}$$

Mean $\theta_1=46°$

Mean $\theta_2=35°$

Solving

$$\log(d^2-l_1^2)=3{\cdot}3894$$
$$\log(d^2-l_2^2)=3{\cdot}3867$$
$$\text{diff.}=0{\cdot}0027\times 2$$
$$=0{\cdot}0054$$
$$\log\tan 46^\circ=\cdot 0152$$
$$\log\tan 35^\circ=\bar{1}{\cdot}8452$$
$$\text{diff}=0{\cdot}1700$$
$$\text{Antilog}=0{\cdot}1754$$
$$=1{\cdot}497$$
$$=1{\cdot}5 \text{ app,}$$

$$d^2=2500$$
$$l_1^2=\ \ 49$$
$$\log\ 2451=3{\cdot}3894$$
$$d^2=2500$$
$$l_2^2=\ \ 64$$
$$\log\ 2436=3{\cdot}3867$$

(*ii*) **Null Method**. Adjust the magnetometer for the 'end-on' position in the same way as before.

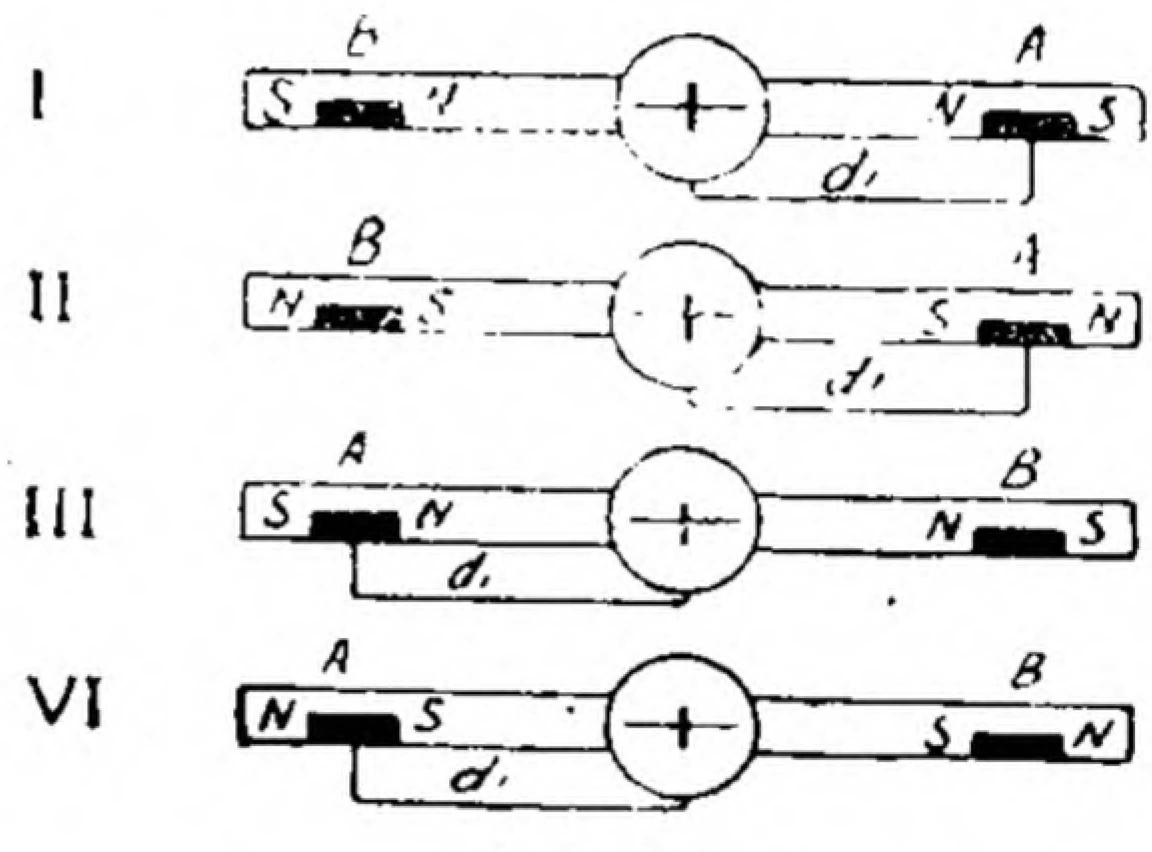


Fig. 135.

In this method the two magnets are placed in the two arms of the magnetometer simultaneously. Place the magnet A in the east arm of the instrument with N, pole facing the needle and adjust the distance of the magnet B as placed in the west arm so that the needle comes back to its original position. Remember that the poles of both the magnets facing the needle should be the same (Position I, Fig. 135). Measure the distance from the middle of magnet A to the centre of the needle and let it be denoted by d_1. Measure the distance from the middle of magnet B to the centre of the needle and let it be denoted by d_2. Keeping the magnet A in the same arm, reverse it so as to interchange the position of the two poles. Let the distance d_1 be kept the same. Adjust the distance of the magnet B by reversing the positions of its poles till the needle comes back to its original position (Position II, Fig. 135). Measure the distance (d_2) from the middle of the magnet to the centre

of the needle. Now interchange the positions of magnets A and B (Position III, Fig. 135). Let the magnet A be placed on the west arm of the instrument with the N pole facing the needle, and the distance d_1 be kept the same as in the previous two cases. Adjust the distance of the magnet B so that the needle remains undeflected. Measure d_2. Now interchange the positions of the two poles of the magnet A so that S pole faces the needle (Position IV, Fig. 135). Keeping the distance d_1 the same adjust the distance of the magnet B by reversing the positions of its poles till the deflection is the same. Measure d_2. Find the mean value for d_2. Calculate $\frac{M_1}{M_2}$ by using the formula

$$\frac{M_1}{M_2}=\frac{(d_1^2-l_1^2)^2}{(d_2^2-l_2)^2}\times\frac{d_2}{d_1}$$

where $2l_1$ represents the length of the first magnet and $2l_2$ the length of the second magnet.

When d_1 and d_2 are both very large as compared to the lengths of the magnets,

$$\frac{M_1}{M_2}=\frac{d_1^3}{d_2^3}.$$

Calculate your result by using the accurate formula and with the help of the logarithmic tables.

Repeat the experiment by changing the distance d_1.

Enter your observations thus :

Length of magnet A, $2l_1=$

,, ,, ,, B, $2l_2=$

No. of observations.	Distance with magnet A d_1	Distance with magnet B				Mean d_2	$\frac{d_1^3}{d_2^3}$
		d_2	d_2	d_2	d_2		
1.							
2.							

$$\frac{M_1}{M_2}=\frac{d_1^3}{d_2^3}.$$

Precautions.—1. Mark the boundary of the magnetometer and level the instrument.

2. Mark the middle line of each magnet.

3. Tap the instrument gently before noting a deflection.

4. Try to have deflection between 25° and 45°.

5. Use a small magnet.

6. Set the arms of magnetometer east and west as accurately as possible.

7. The distance of the magnet from the needle should be large.

Theory.

Since the controlling field (H) due to the earth and the deflecting field (F) due to the magnet are perpendicular to one another, so $F=H \tan\theta$.

But F for magnet $A=\frac{2M_1d_1}{(d_1^2-l_1^2)^2}$ where l_1 is half the length of the magnet and d_1 is the distance of the needle from the middle of magnet.

$$\therefore \; H\tan\theta=\frac{2M_1d_1}{(d_1^2-l_1^2)^2}$$

Similarly with the other magnet,

$H\tan\theta=\frac{2M_2d_2}{(d_2^2-l_2^2)^2}$ the angle of deflection θ being the same in both cases.

$$\therefore \quad \frac{2M_1d_1}{(d_1^2-l_1^2)^2}=\frac{2M_2d_2}{(d_2^2-l_2^2)^2}$$

$$\frac{M_1}{M_2}=\frac{(d_1^2-l_1^2)^2}{(d_2^2-l_2^2)^2}\times\frac{d_2}{d_1}$$

If d_1 and d_2 have large values as compared to l_1 and l_2, then $\frac{M_1}{M_2}=\frac{d_1^3}{d_2^3}$.

Experiment 88.—**To compare the mangnetic moments of two magnets by** (*i*) *deflection method* (*ii*) *null method* **by using the broadside on position of the magnetometer.**

Apparatus.—The same as in the previous experiment.

(1) Deflection method.

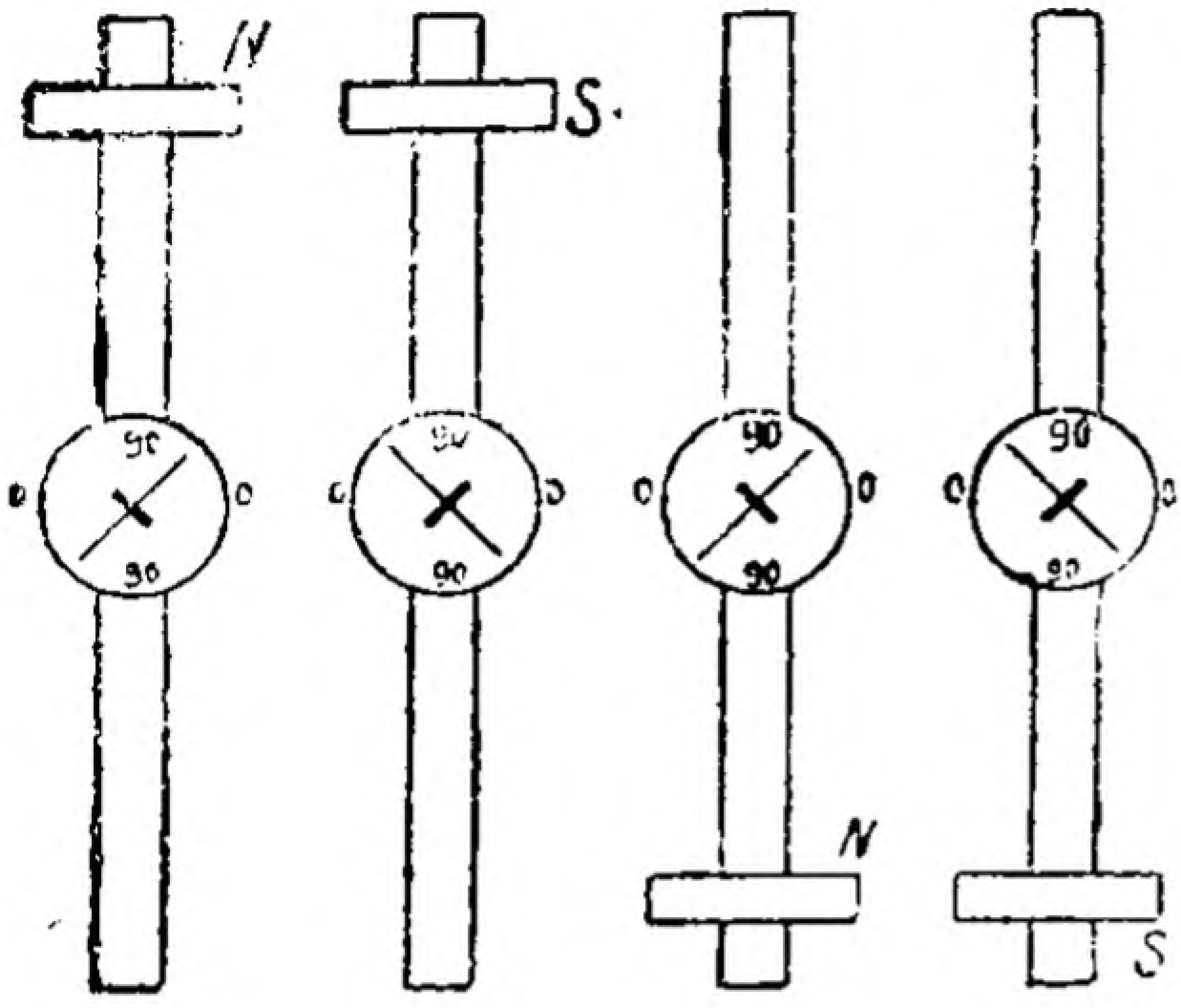


Fig. 136.
Magnetometer in the Broadside-on position

Place the magnetometer so that the arms point north and south (magnetic meridian). In this position the magnetic needle and not the pointer becomes parallel to the arms. Place the magnet A along the N. arm of the magnetometer so that the *axis of the deflecting magnet is along east and west.* Give to the magnet A four positions along the two arms of the magnetometer as shown in the figure keeping the distance the same in all positions. Record your observations as in the previous experiment. Find mean of eight readings and let it to be denoted by θ_1.

Go through the same series of observations with magnet B. Let the mean of eight readings in this case be denoted by θ_2. *The distance in both cases is kept the same.*

Enter your observations in the same way, as in the last experiment.

Theory :—In the 'broadside-on' position we have again two fields at right angles to each other. Hence we have F= H tan θ.

$$\text{But } F=\frac{M_1}{(d_1^2+l_1^2)^{\frac{3}{2}}}=\frac{M_1}{d_1^3\left(1+\frac{l_1^2}{d_1^2}\right)^{\frac{3}{2}}}$$

and in case d_1 is large as compared to the length of the magnet, l_1^2/d_1^2 will become negligible.

$$\therefore \qquad F=\frac{M_1}{d_1^3}=H\tan\theta_1.$$

Similarly for the second magnet, $F=\frac{M_2}{d_2^3}=H\tan\theta_2$

If $\qquad d_1=d_2$, then

$$\frac{M_1}{M_2}=\frac{\tan\theta_1}{\tan\theta_2}.$$

NOTE.—In case suitable deflections are not obtained by placing both the magnets at the same distance, place the two magnets at different distances to get reasonable deflections, and measure the distances carefully.

Then with the first magnet,

$$F=\frac{M_1}{(d_1^2+l_1^2)^{\frac{3}{2}}}=H\tan\theta_1$$

and with the second magnet,

$$F=\frac{M_2}{(d_2^2+l_2^2)^{\frac{3}{2}}}=H\tan\theta_2$$

$$\therefore \qquad \frac{\tan\theta_1}{\tan\theta_3}=\frac{M_1}{(d_1^2+l_1^2)^{\frac{3}{2}}}\times\frac{(d_2^2+l^2_2)^{\frac{3}{2}}}{M_2}$$

or

$$\frac{M_1}{M_2}=\frac{\tan\theta_1}{\tan\theta_2}\times\left\{\frac{(d_1^2+l_1^2)}{(d_2^2+l_2^2)}\right\}^{\frac{3}{2}}$$

(2) Null Method

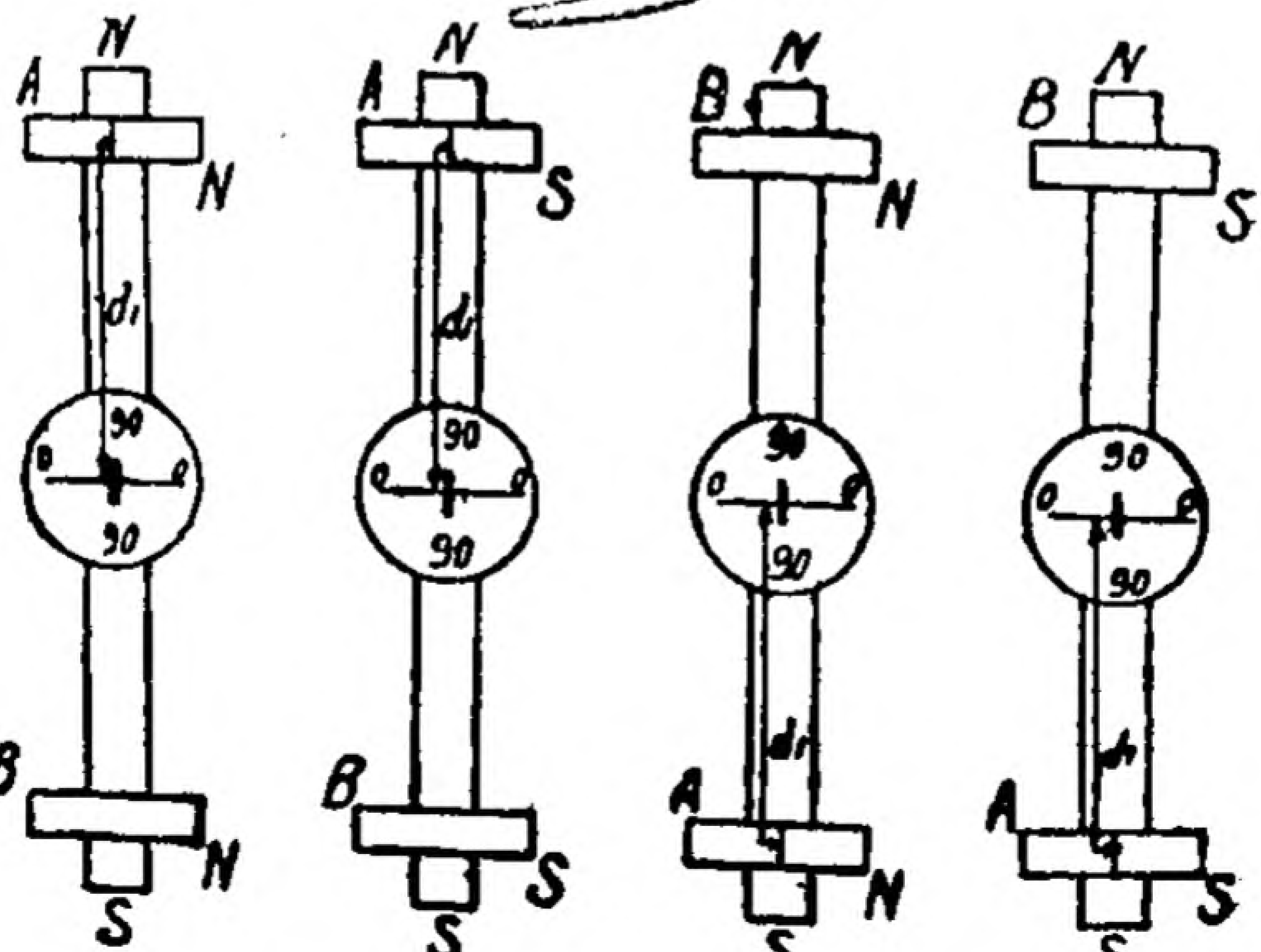


Fig. 137.

Adjust the magnetometer as before. Place the magnet A along the N arm of the instrument and the magnet B along the S arm and adjust their distances till the needle remains undeflected. Note the distance d_1 of magnet A and d_2 of magnet B. Keeping the distance d_1 of magnet A constant, find d_2 for magnet B in different positions, as explained in the null method of the last experiment. Find the mean of d_2.

Enter your observations in the same way, as in the last experiment.

$$\frac{M_1}{M_2}=\frac{d_1^3}{d_2^3}.$$

Theory. If F denotes the field due to the magnet, H the field due to the earth and θ the angle of deflection, $F=H\tan\theta$, since the two fields are perpendicular to one another.

$\therefore$ $\frac{M_1}{d_1^3}=H\tan\theta$, and $\frac{M_2}{d_2^3}=H\tan\theta$ where d_1 and d_2 denote the distances of the needle from the centres of the magnets whose moments are M_1 and M_2 respectively.

$\therefore$ $\frac{M_1}{M_2}=\frac{d_1^3}{d_2^3}$ provided the deflection is the same. If d_1 and d_2 are not large as compared to the lengths of the magnets, we have

$F=\frac{M_1}{(d_1^2+l_1^2)^{3/2}}=H\tan\theta$ for the first magnet and

$F=\frac{M_2}{(d_2^2+l_2^2)^{3/2}}=H\tan\theta$ for the second magnet

Hence $$\frac{M_1}{(d_1^2+l_1^2)^{3/2}}=\frac{M_2}{(d_2^2+l_2^2)^{\frac{3}{2}}}$$

or $$\frac{M_1}{M_2}=\left\{\frac{d_1^2+l_1^2)^{\frac{3}{2}}}{d_2^2+l_2^2}\right\}$$

Experiment 89.—**To prove the law of inverse squares by using the deflection magnetometer.**

Apparatus. Magnetometer, magnet, metre scale, set squares.

Method. Set the magnetometer for the 'end-on' position. Place the given magnet at some distance in one of the arms of the magnetometer and read the deflections of both ends of the pointer. By placing the magnet in different positions along the two arms of the instrument and keeping the distance constant, find the mean of eight readings of the deflection. Let this be θ_1.

Now set the magnetometer for the 'broadside-on' position. Keeping the distance the same, find the mean of eight observations of the deflection. Let it be θ_2.

Find the ratio of $\tan\theta_1$ to $\tan\theta_2$. If $\tan\theta_1/\tan\theta_2$ is equal to 2, the law is proved.

Theory. In the 'end-on' position $F_1=\dfrac{2M}{d^3}$ and in the 'broadside-on' position $F_2=\dfrac{M}{d^3}$.

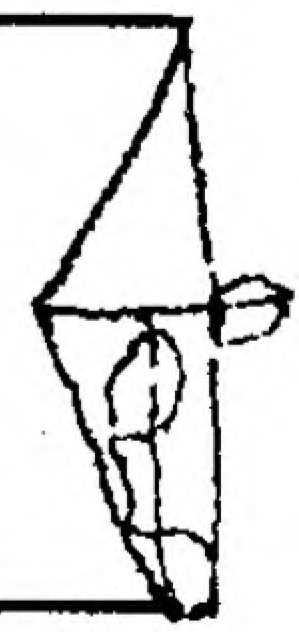
M and d are the same in both cases.

$$\therefore \qquad \frac{F_1}{F_2}=2.$$

But $\dfrac{F_1}{F_2}=\dfrac{\tan\theta_1}{\tan\theta_2}$; hence $\dfrac{\tan\theta_1}{\tan\theta_2}=2$ and this will be true only if $d^2>l^2$.

Enter your observations thus :

Distance	End-on position				Broadside-on position				$\dfrac{\tan\theta_1}{\tan\theta_2}$
	E. arm		W. arm		N. arm		S. arm		
	N.P. foremost	S.P. foremost	N.P. foremost	S.P. foremost	1st position	inverted	2nd position	inverted	
	1.	3.	5.	7.	1.	3.	5.	7.	
	2.	4.	6.	8.	2.	4.	6.	8.	
	Mean θ_1				Mean θ_2				



Take a few more observations.

Oral questions .—

(1) Why do we use a small magnetic needle ?

(2) Why do we use a pointer made of aluminium ?

(3) For determining θ why should you take eight observations ?

(4) Why is a plane mirror placed below the pointer ?

NOTE.—(1) Null method is more accurate than the deflection method.

(2) 'End-on' position is preferable to 'broadside-on' position because in the former case the field is twice that in the latter case. Bigger deflections are obtained in the first case than in the second case .

Exercises.

(1) Plot a graph between the distance of a magnet and tangent of the angle of deflection in the 'end-on' position.

(2) Plot a curve between $\frac{1}{d^3}$ and $\tan\theta$ in the 'end-on' position of the magnet with respect to the magnetometer.

(3) Given H=·329, find the magnetic moment of the given magnet : or from the known value of the magnetic moment of the magnet, find H with the help of deflection magnetometer.

[*Hint*. Adjust the magnetometer for the 'end on' position. By placing the magnet at some distanee from the needle note the deflection produced.

$$F=H\tan\theta, \text{ and } F=\frac{2M}{d^3}.$$

$$\therefore \quad \frac{2M}{d^3}=H\tan\theta \text{ or } M=\frac{d^3\times H\tan\theta}{2}.$$

This formula enables us to calculate magnetic moment and from the known value of M we can calculate H.]

(4) Compare the earth's horizontal field at two places by using the deflection magnetometer.

[*Hint*. Let H_1 and H_2 be the intensities of the earth's field at two places.

With the help of magnetometer placed at the first place, find the deflection produced by a magnet placed at a known distance from the centre of the needle. Let θ_1 be the mean of eight readings. Then move the instrument to the other place, and again find the deflection produced by the same magnet placed at the same distance from the centre of the needle. Let θ_2 be the mean of eight readings.

$$\frac{2M}{d^3}=H_1 \tan \theta_1 \text{ and } \frac{2M}{d^3}=H_2 \tan \theta_2.$$

$$\therefore \qquad H_1 \tan \theta_1=H_2 \tan \theta_2 \text{ or } \frac{H_1}{H_2}=\frac{\tan \theta_2}{\tan \theta_1}$$

This experiment can also be tried by keeping the deflection same.

$$\left.\frac{H_1}{H_2}=\frac{d_2^3}{d_1^3}.\right]$$

(5) Take two knitting needles and magnetise them. Compare their magnetic moments by using the deflection magnetometer. Hammer one of them gently, and again compare their magnetic moments.

(6) *Plot a graph between d^3 and $\cot \theta$ by using the deflection magnetometer.*

CHAPTER XXVII

METHOD OF OSCILLATIONS

Comparison of magnetic moments of magnets and of the strength of magnetic fields.

When a magnet of magnetic moment M is allowed to vibrate in a magnetic field of intensity H, the period of vibration T, is given by the formula, $T = 2\pi\sqrt{\frac{K}{MH}}$ where K is a constant that depends upon the mass and dimensions of the magnet. It is called the **moment of inertia**. of the magnet.

For a *rectangular bar magnet* $K = w\left(\frac{l^2+b^2}{12}\right)$, where l and b are the length and the breadth of the magnet respectively, and w the mass of the magnet.

For a *cylindrical magnet*, $K = w\left(\frac{l^2}{12} + \frac{d^2}{16}\right)$ where d is the diameter of the magnet which can be measured with vernier calipers.

$$\therefore \quad T = 2\pi\sqrt{\frac{K}{MH}} \text{ or } T^2 = \frac{4\pi^2 K}{MH}$$

$\therefore$ $MH = \frac{4\pi^2 K}{T^2} = 4\pi^2 K n^2$ where n is the frequency (number of vibrations per second) $n = \frac{1}{T}$.

Vibration Magnetometer. It consists of wooden box having glass on all sides. The front side of the box opens like a window.

The magnet is held in the double loop of silk support which is suspended from the top of the box. Sometimes a brass stirrup is used to support the magnet, which must be suspended by *unspun silk*. No thread of silk or cotton be used for suspension as it untwists under the action of weight, causing the magnet to turn round and round.

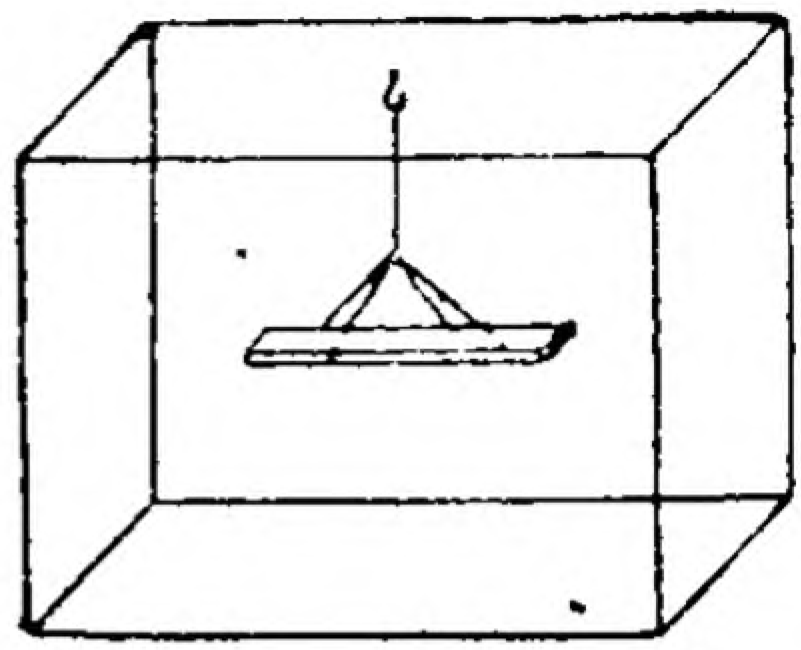


Fig. 138.

The suspension is free from twist when it has no tendency to turn one way or the other.

The box has two slits in the top through which the oscillations of the magnet can be watched. The magnet is supported from a torsion head at the top of a glass-tube.

The object of using a box is to protect the magnet from air currents. A bell jar would serve the same purpose.

Experiment 90. **To compare the magnetic moments of two magnets by the method of oscillations. (Magnets are of same mass, size and shape.)**

Apparatus.—Vibration box, two identical magnets, unspun silk (***Putt***), stop watch, a piece of chalk and a metre rod.

Method.—Making use of a compass needle place the longest edge of the vibration box along the north and south direction. (There is a line on the mirror attached to the bottom of the vibration box and it can help in placing the box in the desired position.) Take a brass rod and place it in the stirrup and if there is any twist in the silk thread it will turn round and round till the twist is removed. When the rod becomes stationary, turn the torsion head through a small angle till the rod becomes parallel to the north and south direction. In this way the twist in the silk thread will be removed and the brass rod will be resting along the magnetic meridian. Now replace the brass rod by a magnet and it will remain at rest in this position without giving any twist to the thread. By bringing a piece of iron outside the box, allow the suspended magnet to vibrate.

The amplitude of vibration must be small and the magnet should not move bodily towards east and west. Find the time of 10 or 15 vibrations with the help of stop-watch. Repeat the observations 3 or 4 times and find the mean. Now substitute the second magnet for the first and find the time of 10 or 15 vibrations with your stop-watch. Repeat it 4 times and find the mean of 4 observations.

Enter your observations as follows :—

Magnets	Time of vibration (1)	(2)	(3)	(4)	Mean	Time of one vibration (Period)	Frequency	$\frac{t_2^2}{t_1^2}$	$\frac{n_1^2}{n_2^2}$
A						t_1	n_1		
B						t_2	n_2		

$$\therefore \frac{M_1}{M_2} = \cdots\cdots\cdots$$

Theory. Let t_1 and t_2 be the time periods in the two cases, K_1 and K_2 the moments of inertia, M_1 and M_2 the magnetic moments of the magnets and H the field in which they are suspended.

$$t_1 = 2\pi\sqrt{\frac{K_1}{M_1 H}} \quad \text{or} \quad t_1^2 = \frac{4\pi^2 K_1}{M_1 H}$$

and

$$t_2 = 2\pi\sqrt{\frac{K_2}{M_2 H}} \quad \text{or} \quad t_2^2 = \frac{4\pi^2 K_2}{M_2 H}$$

$$\frac{M_1}{M_2} = \frac{t_2^2}{t_1^2} \times \frac{K_1}{K_2}$$

Since $K_1 = K_2$ therefore $\frac{M_1}{M_2} = \frac{t_2^2}{t_1^2}$.

If n_1 and n_2 were to denote the frequencies,

$$\frac{M_1}{M_2} = \frac{n_1^2}{n_2^2}.$$

Experiment 91. **To compare the magnetic moments of two magnets by *sum and difference method* when two magnets of different moment of inertia are supplied.**

Apparatus. Vibration box, two magnets of different masses and dimensions, stop watch, unspun silk, a metre rod.

Method. First by a compass needle place the longest edge of the vibration box along the north, south direction. By using a brass rod remove twist from the silk thread by which the stirrup is suspended from a torsion head. Move the torison head through a small angle so that the rod becomes parallel to the north, south direction. Replace the rod by two magnets with their like poles pointing in the same direction supported by two holes in a block of wood or in the stirrup. Find the time of 10 or 12 vibrations with a stop watch. Let T_1 denote the time period.

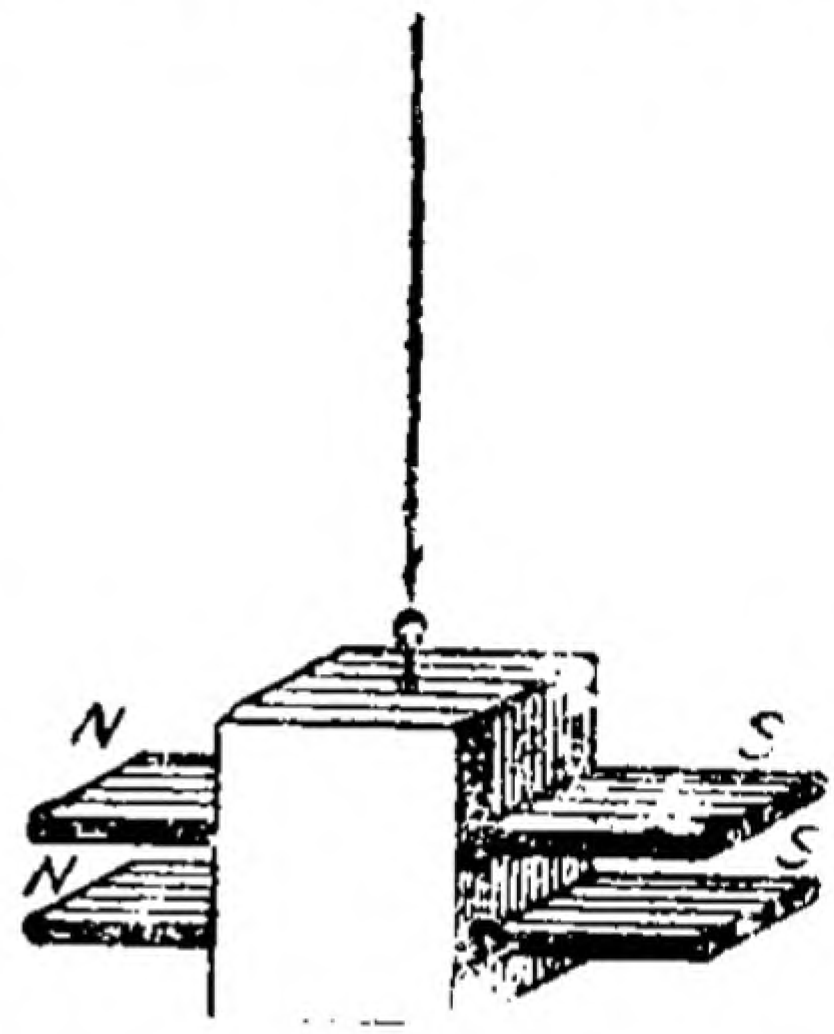


Fig. 139.

Now reverse the polarity of the weaker magnet. The magnet should be arranged symmetrically so that their parallel axes are in the same vertical plane. In this way the moment of inertia of the combination will remain the same when the poles are reversed. Again find the time of 10 or 12 vibrations. Let T_2 denote the time period.

$$T_1=2\pi\sqrt{\frac{K_1+K_2}{M_1+M_2}} \quad \text{or} \quad T_1^2=\frac{4\pi^2(K_1+K_2)}{M_1+M_2},$$

where K_1 and K_2 are the moments of inertia of the two magnets of magnetic moments M_1 and M_2 respectively.

$$T_2=2\pi\sqrt{\frac{K_1+K_2}{M_1-M_2}} \quad \text{or} \quad T_2^2=\frac{4\pi^2(K_1+K_2)}{M_1-M_2}$$

$$\therefore \quad \frac{M_1+M_2}{M_1-M_2}=\frac{T_2^2}{T_1^2}$$

$$\text{or} \quad \frac{M_1}{M_2}=\frac{T_2^2+T_1^2}{T_2^2-T_1^2}$$

NOTE. *The sum and difference method is not applied when magnets are of nearly equal magnetic moments.* In such cases, calculate the moments of inertia of each magnet, by carefully measuring the dimensions and masses of the two magnets and then compare the magnetic moments by using the following relation :

$$\frac{M_1}{M_2}=\frac{T_2^2}{T_1^2}\times\frac{K_1}{K_2}.$$

Tabulate your observations for such a case in the following manner :

Magnets of inertia	Time period	$\frac{M_1}{M_2}=\frac{T_2^2K_1}{T_1^2K_2}$
$K_1=$	$T_1=$	
$K_2=$	$T_2=$	

Experiment 92. **To compare the intensities of two fields by the method of oscillations.**

Apparatus. Vibration box, two magnets, stop-watch, unspun silk, blocks, a metre-stick.

Method. Suspend a magnet in the earth's field and note the time for 10 or 12 vibrations. Repeat this 3 or 4 times and find the mean value for the time period. Let T_1 represent the time period.

Place another magnet on a block of wood at a level with the suspended magnet and towards its south. Let the north pole of the second magnet point towards the north. The field F due to the magnet is in the same direction as the horizontal field H due to the earth. Find the time of 10 or 12 vibrations of the suspended magnet under the action of new field (F+H) and then find the mean. Let T_2 represent the time period.

The field F is supposed to be stronger than H.

$$\frac{F+H}{H}=\frac{T_1^2}{T_2^2}$$

This equation also enables us to calculate the field F due to the magnet, if the value of H be known.

$$\frac{F}{H}+1=\frac{T_1^2}{T_2^2} \text{ or } F=H\left(\frac{T_1^2}{T_2^2}-1\right)$$

H=·329 C. G. S. units.

If the second magnet had been placed so as to have its S. pole towards the north, the field F due to the magnet would have opposed the field H due to the earth. The resultant field would have been (F−H).

Tabulate your observations as follows :

Time of vibration in the earth's field (H)					Time of one vibration T_1	Time of vibration in the combined field F+H					Time of one vibration T_2	$\frac{F+H}{H}=\frac{T_1^2}{T_2^2}$
(1)	(2)	(3)	(4)	Mean		(1)	(2)	(3)	(4)	Mean		

Theory.

$$T_1=2\pi\sqrt{\frac{K}{MH}} \text{ or } T_1^2=\frac{4\pi^2K}{MH}$$

$$\text{or } H=\frac{4\pi^2K}{M}\times\frac{1}{T_1^2}$$

$$T_2=2\pi\sqrt{\frac{K}{M(F+H)}} \text{ or } T_2^2=\frac{4\pi^2K}{M(F+H)}$$

$$\text{or } (F+H)=\frac{4\pi^2K}{M}\times\frac{1}{T_2^2}$$

$$\therefore \frac{F+H}{H}=\frac{T_1^2}{T_2^2}.$$

[NOTE.—We can get the new field in another way. If the vibration box be supported on blocks of wood, the second magnet can be placed below the box on the table along the magnetic meridian. If the N. pole is towards the north, the second field is F+H, and if the N. pole is towards the south the second field is F−H.]

Experiment 93. **To determine H (horizontal component of the earth's force) at a given place.**

Apparatus. Deflection magnetometer, vibration box, magnet, stop-watch, unspun silk, set squares, metre-stick.

Method. Adjust the deflection magnetometer for the 'end-on' position, and note the angle of deflection by keeping the magnet at a suitable distance from the centre of the pivoted needle. Find the mean of 8 readings as explained in deflection magnetometer experiments. Let θ be the angle of deflection and d the distance between the centre of the needle and the middle of the magnet. Determine the value of M/H from this part of the experiment.

$$F = H \tan\theta \quad \text{or} \quad \frac{2M}{d^3} = H \tan\theta \qquad (i)$$

$$\therefore \frac{M}{H} = \frac{d^3 \tan\theta}{2}$$

Next suspend the magnet inside the vibration box according to the manner explained in previous experiments, and note the time of 10 or 12 vibrations with a stop watch. Repeat it 3 times and find the mean and calculate the time period. Let T denote the time period of the suspended magnet of moment of inertia K. This part of the experiment enables us to determine the value of MH.

$$T = 2\pi\sqrt{\frac{K}{MH}} \quad \text{or} \quad T^2 = \frac{4\pi^2 K}{MH}$$

$$\therefore MH = \frac{4\pi^2 K}{T^2} \qquad (ii)$$

On dividing the (*ii*) equation by the (*i*) we get

$$MH \times \frac{H}{M} = \frac{4\pi^2 K}{T^2} \times \frac{2}{d^3 \tan\theta}.$$

$$H^2 = \frac{8\pi^2 K}{T^2 d^3 \tan\theta}.$$

Calculate the value of $\frac{M}{H}$ and MH separately, and then divide.

Enter your observations as follows :
Length of Magnet $(l)=$
Breadth of Magnet $(b)=$

Mass of the Magnet $(w)=$

$K = w\left(\frac{l^2+b^2}{12}\right)$ for a rectangular magnet, where w is the weight of magnet and l and b are its length and breadth.

Deflection Magnetometer							Vibration Magnetometer					H
	E arm		W arm		mean θ	tan θ	Total Time				T	
d	N to E	N to W	N to E	N to W			(1)	(2)	(3)	(4)		

NOTE.—We can find the value of M (magnetic moment of the magnet) if H be known. Instead of dividing the second equation by the first, multiply the two equations together.

$$\frac{M}{H} \times MH = \frac{d^3 \tan\theta}{2} \times \frac{4\pi^2 K}{T^2}$$

$$\text{Or } M^2 = \frac{2\pi^2 K}{T^2} \times d^3 \tan\theta.$$

Exercises

(1) *Prove the law of inverse squares by the method of oscillations.*

[*Hints.* Clamp a magnet vertically by using a retort stand, with its S. pole uppermost. Place a magnetic needle so that the N. pole of the magnet faces the south pole of the needle. Let d_1 be the distance between the centre of the needle and the N. pole of the magnet. Count the number of vibrations in a certain time ; and call the frequency n_1. Placing the magnet at a distance d_2 from the needle, find the frequency n_2. Take the vertical magnet far away from the needle and find the frequency in the earth's field alone ; call it n. Let F_1 be the force in the first position and F_2 the force in the second position. The effect of the S. pole of the magnet may be considered negligible.

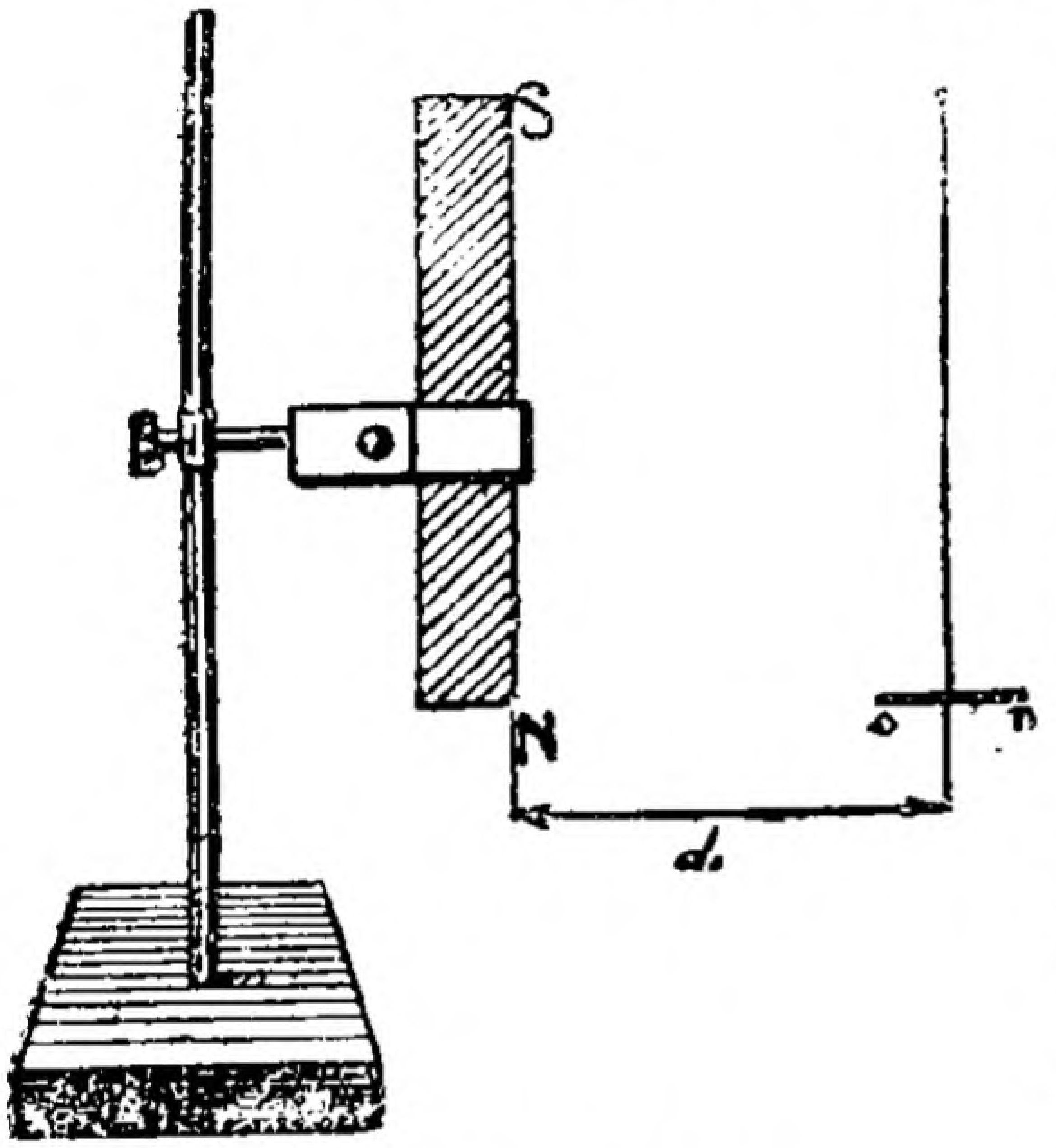


Fig. 140.

Hence $\frac{F_1}{F_2}=\frac{n_1^2-n^2}{n_2^2-n^2}$ But from the experiment it will be found that $\frac{n_1^2-n^2}{n_1^2-n^2}=\frac{d_2^2}{d_1^2}$ $\therefore \frac{F_1}{F_2}=\frac{d_2^2}{d_1^2}$

In other words force is inversely proportional to the square of the distance.

(3) Compare the relative quantities of free magnetism along the length of a bar magnet.

[*Hints.*—Clamp a magnet vertically with its N. pole uppermost by using a retort stand. Divide the magnet into a number of equal parts and mark the divisions with a piece of chalk. Place a small magnetic needle which is pivoted or suspended so that it is quite close to the magnet. Let the magnet be placed so that the direction of the needle is not disturbed. The N. pole of the magnet is due south of the magnetic needle. Disturb the needle slightly with your pencil or by bringing a piece of iron near it and find the frequency n_1. Similarly find the frequency opposite to each point of the magnet. Let n_2 be the frequency opposite to the next point and so on. Find the frequency n in the earth's field alone. The force at the different points will be proportional to $(n_1^2-n^2)$, $(n_2^2-n^2)$, and so on.

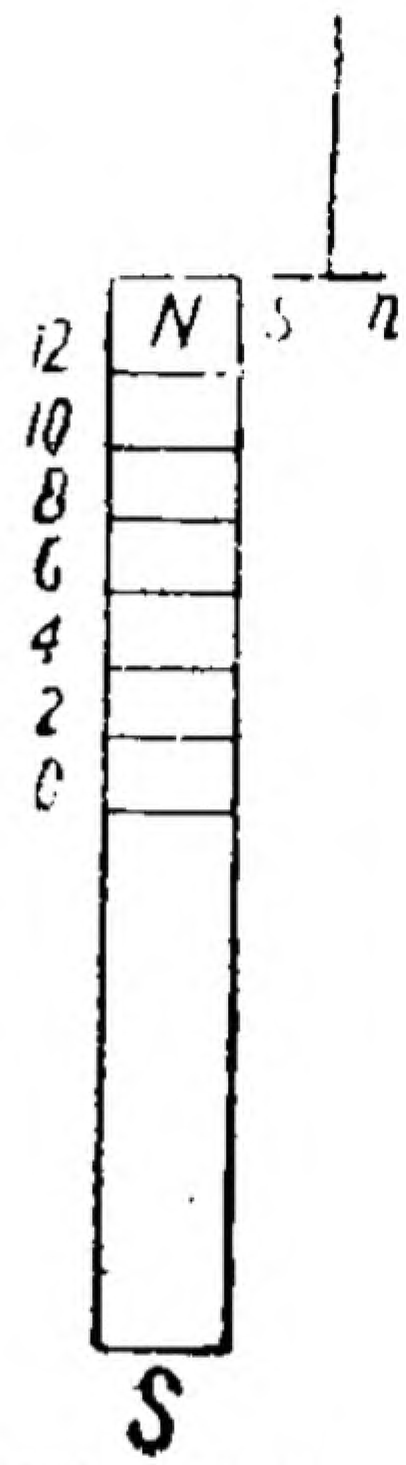


Fig. 141.

Place the magnet on a paper and draw its boundary and mark the position of different points along its length. Erect perpendiculars at the different points and let the lengths of the perpendiculars be proportional to respective forces represented by $(n_1^2-n^2)$, $(n_2^2-n^2)$, and so on. Draw the graph to show the distribution of free magnetism along the length of the bar magnet.

(3) Compare the values of magnetic force due to the given magnet at points on its axis 12 and 16 cm., beyond one end.

CURRENT ELECTRICIY

CHAPTER XXIX

SOURCES OF CURRENT, ARRANGEMENT OF CELLS, COMMUTATORS AND KEYS.

When the ends of a conductor are kept at two different potentials, a current begins to flow in it. In order to send a steady current in the conductor, it is necessary to maintain the difference of potential at a constant value.

Sources of current. For experimental work in the laboratory, domestic and industrial purposes, there are two sources of electric currents :—

(1) **Electric supply mains of the city.** Here the two mains are kept at a definite difference of potential which is generally 220 or 110 volts. If the current always flows in one direction, the supply is said to be D. C. (Direct current), and if the direction changes sevreal times in a second, it is called A. C. (Alternating current). In using the current from the city mains, very great care should be taken, otherwise one may get a severe shock.

(2) **Cells** (*primary and secondary*). For generating small electric currents for intermittant use and especially for experimental work, the students will find the cells and accumulators very useful. The following remarks about their use will assist him in selecting the most appropriate sources in the experiment which he is going to do. The dry cells which are used for ringing door bells and operating flash lights, telephones and radio sets etc. are also included under this head.

When two conductors are placed in a solution which acts more on one than on the other, a difference of potential is set up between the two conductors and when they are joined together, a current begins to flow from the one at the higher potential to the other at the lower potential.

It is customary to call the plate which is attacked less as positive (+) (the copper) and the other negative (−) (the zinc). Different experimenters have worked with different pairs of conductors and solutions and as a result of their investigations, the following cells have come in common use in laboratories. We will give here only their description; for details as regards their chemistry, etc., a text-book on electricity may be consulted.

Daniel Cell (Fig. 142). It consists of an outer copper-vessel in which a saturated solution of copper sulphate is put. In the solution is placed a porous pot containing dilute sulphuric acid (1 vol. of strong sulphuric acid with 12 vols. of water) or saturated solution of zinc sulphate. The porous pot has in it a zinc rod. Round the inside of the copper vessel a shelf is often fitted and crystals of copper sulphate are placed on it to keep the solution saturated. The hydrogen which is evolved by the action of zinc on sulphuric acid, passes through the porous pot to reach the copper plate and combines with copper sulphate and deposits copper on the inside of the copper vessel. Since the zinc gradually dissolves it should be a thick rod.

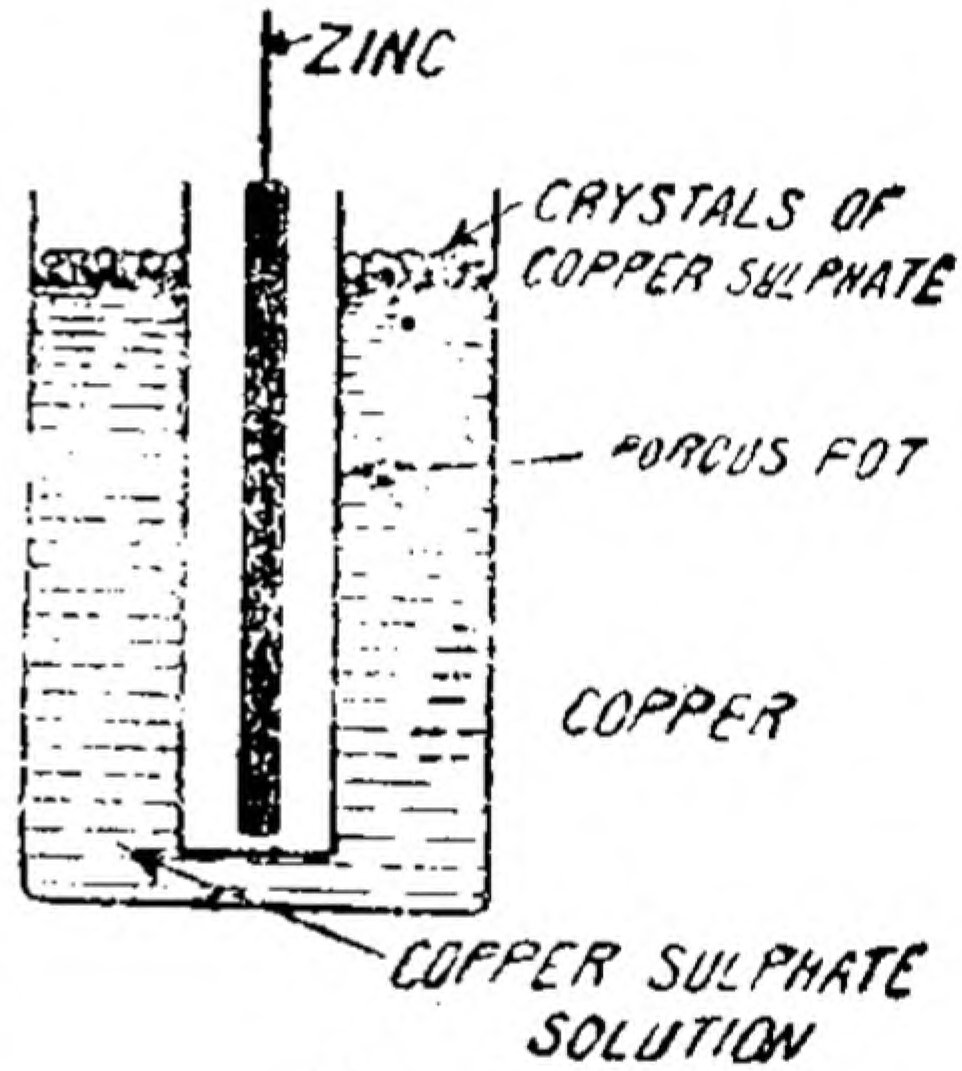


Fig. 142.

E. M. F. of a Daniel cell is 1·08 volts, and it gives a fairly steady current.

It can be used in all experiments on measurement of resistances and where a steady current is required for a short time.

The cell should be dismantled immediately after an experiment, otherwise the two liquids, copper sulphate and dilute sulphuric acid, tend to diffuse and mix with each other. The zinc rod should be washed and porous pot should be soaked in a deep dish of water and not simply *swilled*.

Leclanche Cell (Fig. 143). It contains a carbon plate packed round with manganese dioxide and pieces of carbon in a porous cell, which is placed in a glass vessel containing solution of sal ammoniac (ammonium chloride). There is also an amalgamated zinc rod in the solution. The hydrogen which is formed by the action of zinc on ammonium chloride tends to be evolved at the carbon plate and reduces the manganese dioxide and gets itself oxidized to form water. If, the cell is short circuited and is used for a long time or draws a large current, it gets polarized very soon, but recovers if disconnected and allowed to stand. This cell is useful for intermittant work, *i. e.*, for ringing bells and telegraphy and can be used with advantage where a small but not uniform current is required. Thus this cell can be used for measurement of resistances by Slide-wire bridge and Post-office box methods.

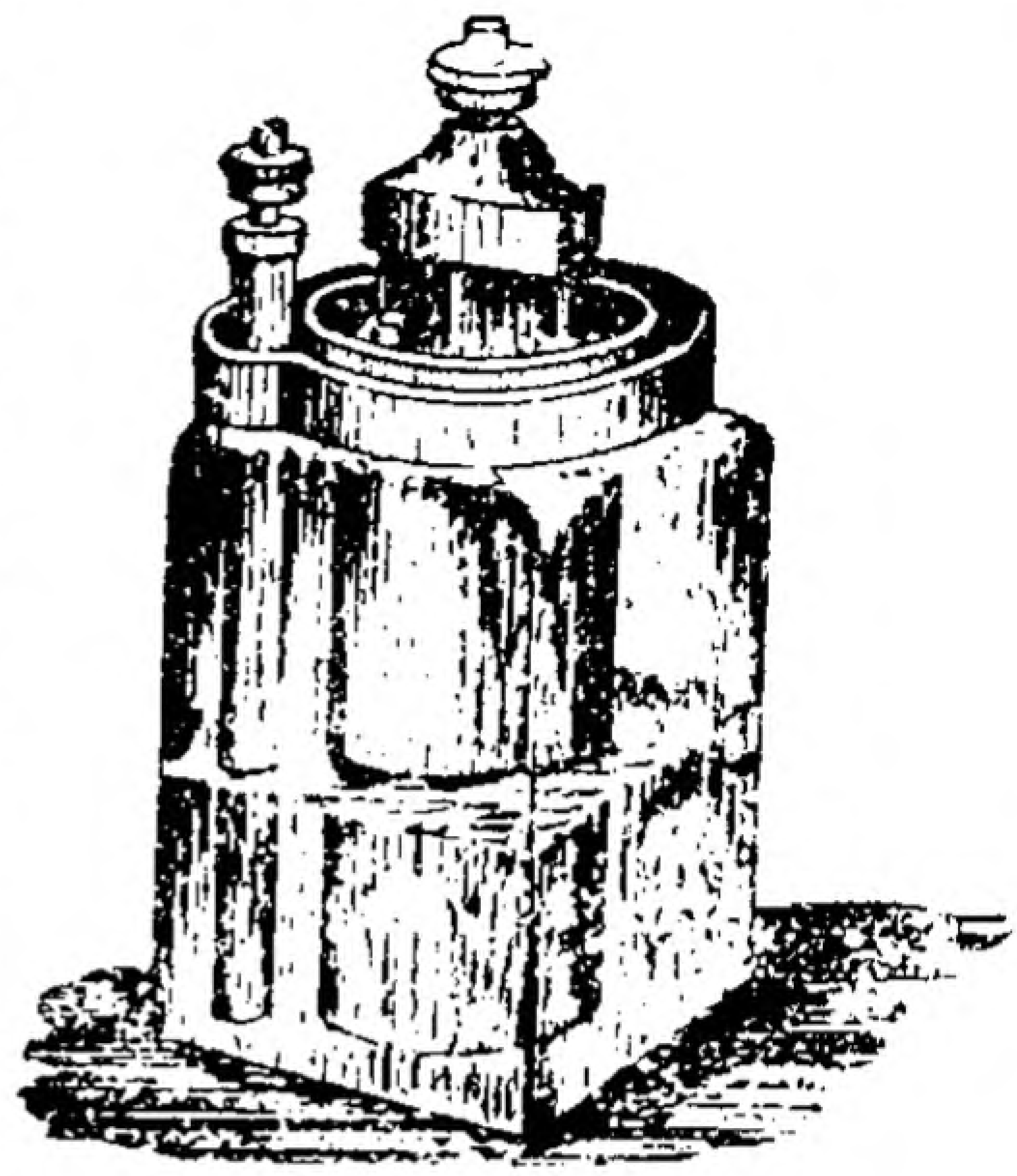


Fig. 143.

Leclanche cells do not require looking after them and they can be left for several weeks without any further attention. E. M.F. is about 1·45 volts.

Bunsen Cell. It consists of an outer earthenware pot having dilute sulphuric acid, (1 vol. acid, 12 vols. water) in it. In the acid is placed an amalgamated zinc cylinder. A porous pot having strong nitric acid and a carbon plate in it is placed so that it is surrounded by the zinc cylinder. The hydrogen in reaching the carbon plate is oxidized by the nitric acid. E. M. F. is 1·9 volts and remains fairly constant. The cell can be used for electroplating purposes and also wherever a steady current is required. Its disadvantage is that it gives pungent fumes of oxides of nitrogen. When the cell is not required, its parts should be taken to pieces and well rinsed with water. The porous pot should be well soaked in water. When after use the nitric acid has acquired

greenish blue colour, it should be replaced by fresh acid. As in this cell, the dilute sulphuric acid is contaminated with nitric acid, it should be kept in a separate bottle and should not be mixed with dilute sulphuric acid to be used in other cells.

Grove Cell. Not much used.

Dry Cells. These are chemically nothing but Leclanche cells and the remarks given in the case of Leclanche cells apply to them.

General remarks about Cells. When using cells, the following precautions should be taken :—

1. Clean with a sand paper the binding screws especially the portion to which the wire is to be screwed. Clean also the portion of the + and − poles at which the screw is to be fixed.

2. See that the zinc rod does not come in contact with the + pole.

3. The liquids used should be of proper strength. Dilute sulphuric acid should be prepared by mixing 1 part of the acid (by volume) to 12 parts of water (by volume).

4. Do not pass the current from the cells unnecessarily when an observation has been taken, the circuit should be broken by removing the plug from the key.

The cell should in no case be short-circuited.

5. When the experiment has been finished, the various parts should be disconnected, cleaned and washed with water. The porous pot should be well soaked in water.

6. Before using the zinc rod, it should be well amalgamated with mercury, otherwise the cell will give a weak current due to local action.

How to amalgamate a zinc rod. Take the zinc rod and to clean its surface dip it in dilute sulphuric acid contained in a vessel until effervescence begins. Next put it in the amalgamating dish and pour mercury over the zinc and rub thoroughly with a piece of cloth until the zinc acquires a bright coating. Tap the rod gently to remove excess of mercury.

Amalgamation should not be done very often, for the zinc becomes rotten.

Accumulators. These are very convenient to use for experimental work and give steady currents. Their internal resistance is very small. The chief disadvantage is that if care is not taken in their use, they get damaged. An accumulator is made of plates of lead, the negative plate is loaded with spongy lead and the positive with peroxide of lead. We should not draw large currents and should be very careful that the accumulator does not get *short circuited*, for even momentary over-load causes very rapid evolution of gas inside as well as outside the plates and the plates buckle and the material with which they are covered is thrown off. The acid of the accumulators should be occasionally tested with the hydrometer and when the specific gravity falls to 1·190 or the voltage decreases to 1·8, the accumulator should be charged. Even when the accumulator has not been used, it will be better to charge it every fortnight. Method of charging will be described later.

When inexperienced students are to work, it will be better to connect one ampere fuse across one terminal and an external binding screw from which current should be taken. In this way more than one ampere of current will not be drawn and chances of damaging the accumulator will be minimised.

The solution (dilute sulphuric acid) slowly evaporates and some of it is lost during charging. When the level of the liquid falls below the acid level line or the upper edge of the plates gets exposed, distilled water should be added to cover the plates again.

E. M. F. of a fully charged accumulator is 2·2 volts.

When using an accumulator, a key should always be inserted in the circuit, so that the current may be stopped at will.

Arrangement of Cells. Two or more cells can be joined together to form a *battery* to give higher E.M.F. or greater current. A cell is generally represented by two parallel lines the short thick line stands for the zinc or negative pole and the long thin one for the copper or positive pole.

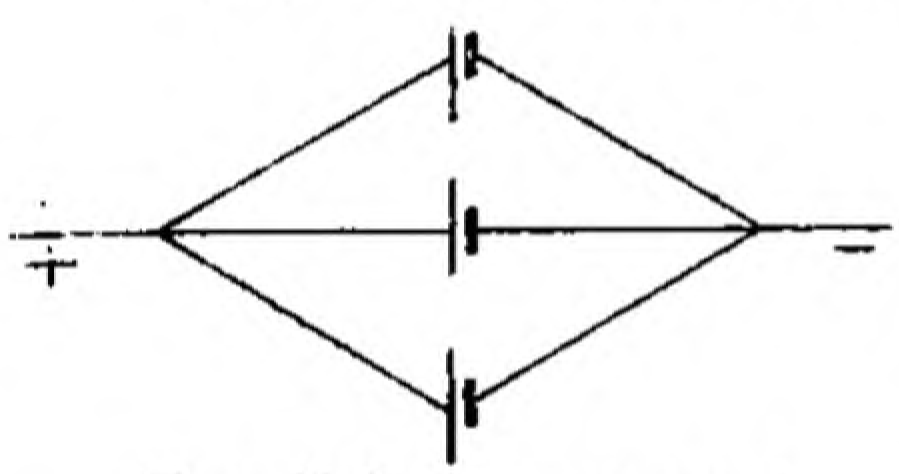
(1) **Series Arrangement**. (Fig. 144 A.) In this arrangement, the positive pole of the first cell is joined with the negative of the second and the positive of the second with the negative of the third and so on, there will thus be left one free positive and one free negative, the current will in this case flow through all the cells. Suppose n cells are arranged and E. M. F. of each cell = E, and internal resistance = B, then E. M. F. of the battery = n E volts.

Series arrangement
Fig. 144 A.

Resistance $= n$ B ohms.

This arrangement is for power, *i.e.*, voltage is increased.

(2) **Parallel Arrangement**. (Fig. 144 B.) In this arrangement all the positive plates are connected together and so are the negatives. The zincs will act like one big zinc plate and the coppers like one big copper plate. The E. M. F. remains the same as that of a single cell, *i.e.*, E, but the internal resistance decreases and becomes $\frac{B}{n}$ ohms.



Parallel arrangement
Fig. 144. B.

(3) Cells may be partly connected in series and partly in parallel as shown in Fig. 144 C.

Keys, Commutators.

When working with electric current, very often it is desired to break or make a circuit or to pass the current in some other branch circuit, this can easily be done by means of keys. When a plug is inserted between the bars of a key, the electric connection is established between them and on removing the plug, the connection is broken.

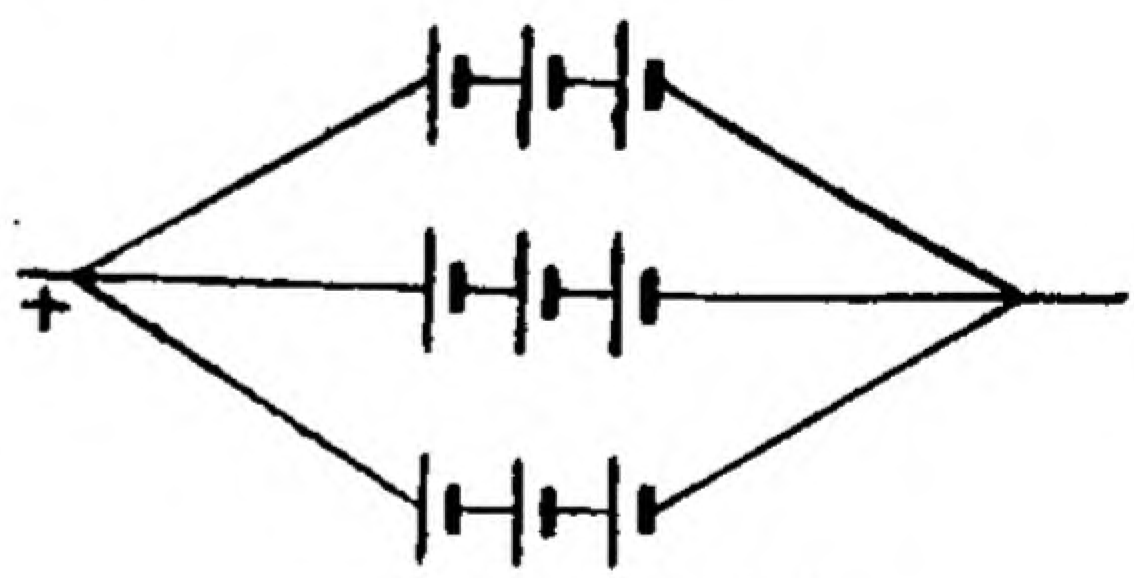


Fig. 144 C.
Mixed arrangement

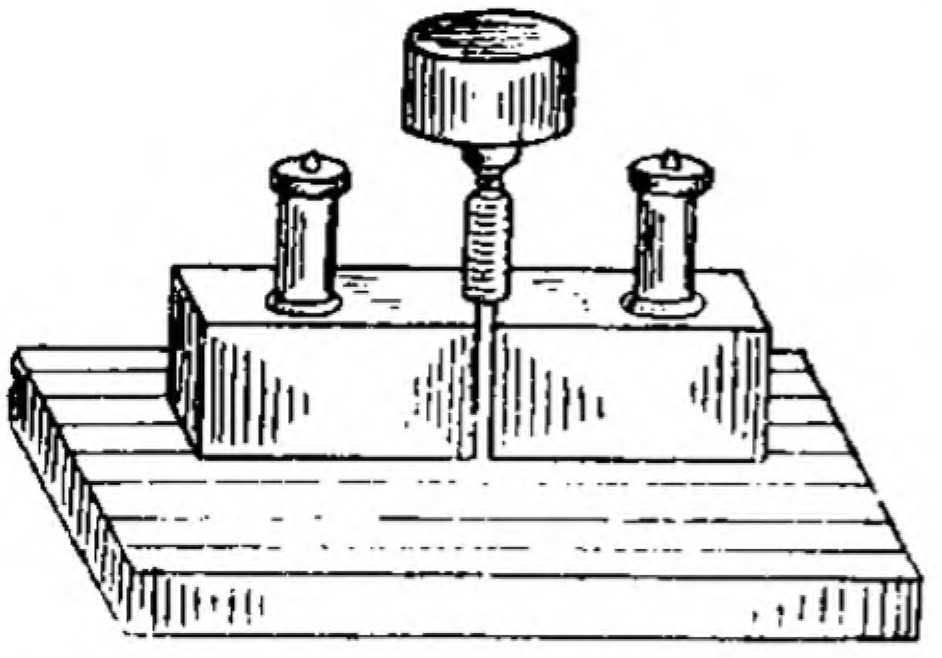
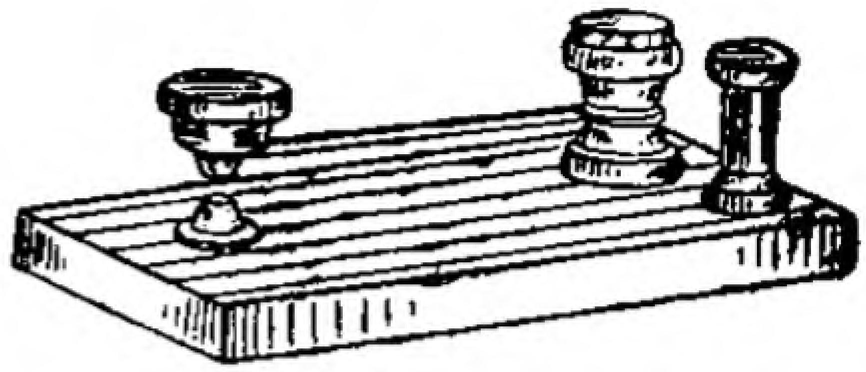


Fig. 145 A.



Simple Press key

Fig. 145 B.

Some of these keys are shown. Fig. 145 A represents a single plug key, it is convenient to use when the current is to be maintained for a considerable time. Fig. 145 B shows a simple press key; on depressing the knob, electrical contact it established. It should be used when the current is to be passed for a moment only.

Fig. 145 C shows a two way key.

Fig. 145 D shows another form of a two way key. Current coming to the bar A can be branched off either to B or C by inserting plugs.

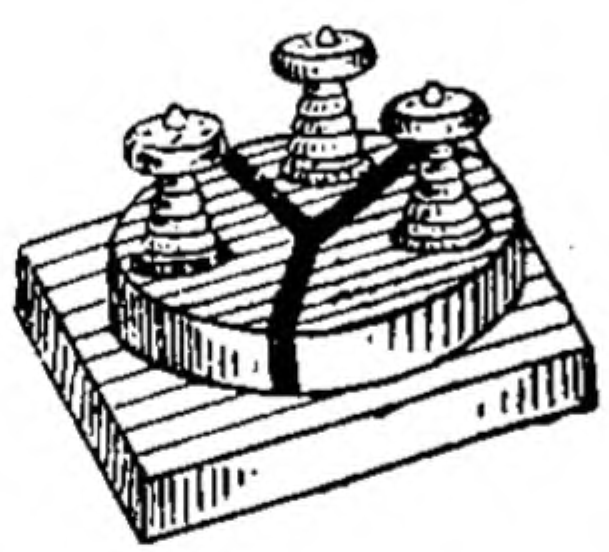


Fig. 145 C.

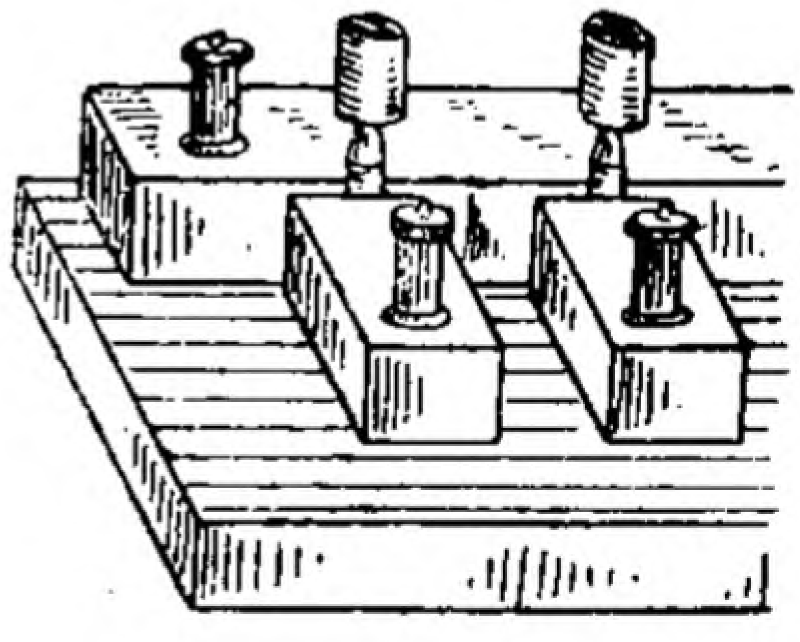


Fig. 145 D.

Very often it is required to reverse the path of a current in a circuit. This can be easily done with the help of commutators, Fig. 146 A, 146 B, 146 C, 146 D.

A is a revolving brush type commutator, sometimes called reversing key. It is very convenient to use.

B is a plug type commutator. C is a Pohl's commutator D is a Bartin's commutator.

Revolving Brush type Commutator. (Fig. 146 A). It consists of a square piece of wood or ebonite having two half brass rings. Each of these rings is provided with a brass terminal G_1, G_2. There is also a revolving arm made of wood or ebonite capable of rotation about its centre. On this arm near the ends are placed two screws B_1, B_2 and

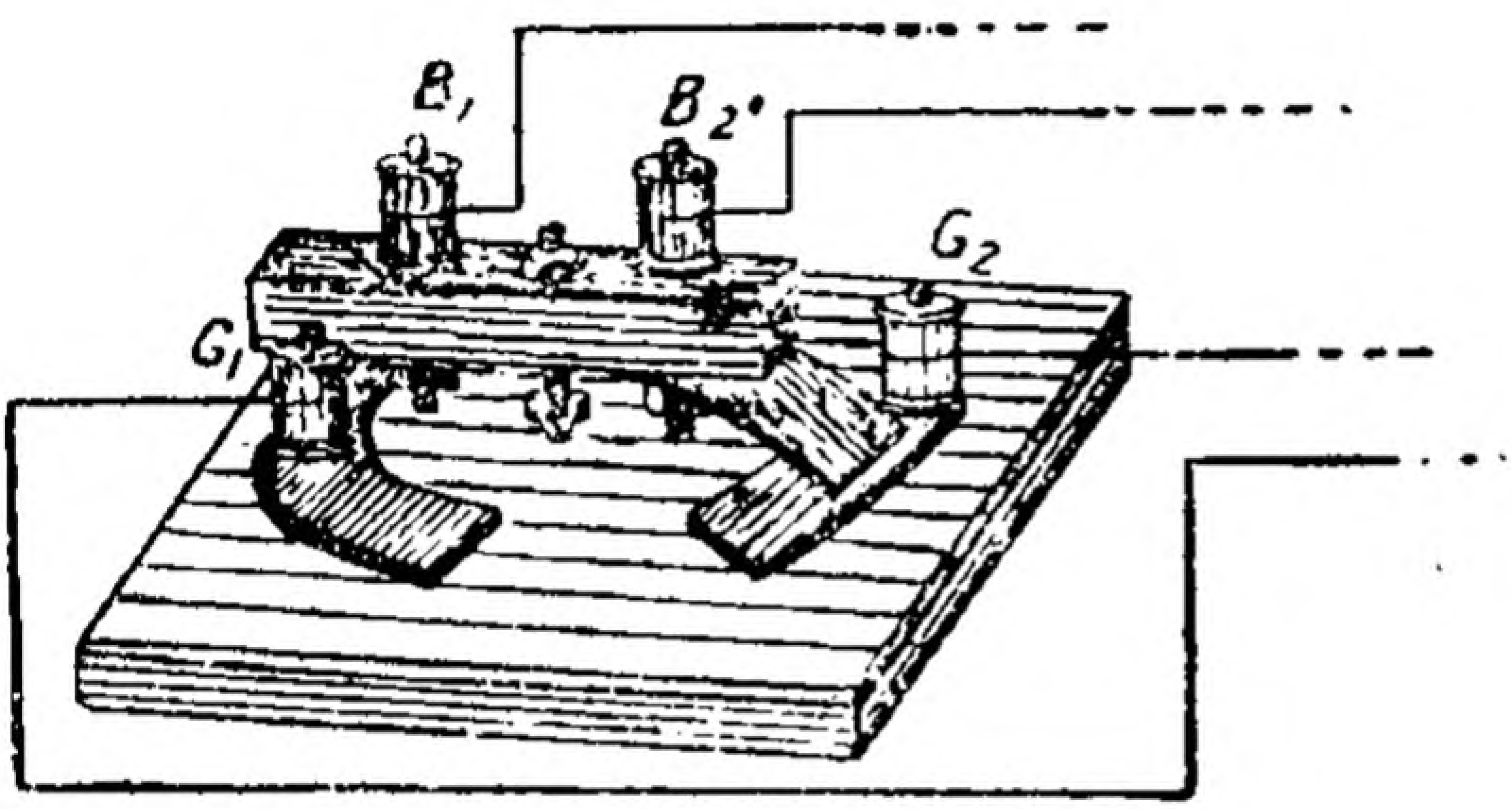


Fig. 146 A.

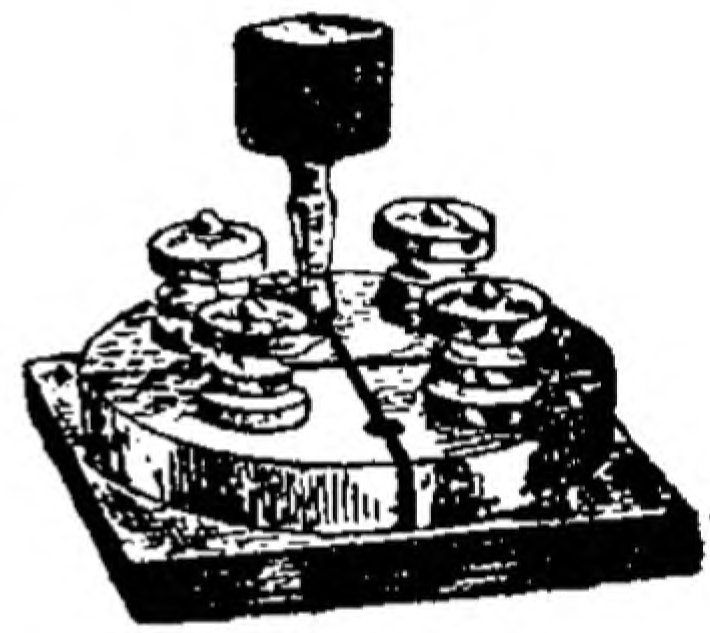


Fig. 146 B.

each of these on the lower side is connected with strong pieces of brass known as brushes. On revolving the arm, the terminals, B_1, B_2 can be placed in contact with G_1 or G_2 as desired through the brushes. The wires from the battery poles may be brought to B_1 and B_2 and the remaining circuit completed through G_1 and G_2. When the brushes are not resting on the rings, no current can pass through the apparatus. This type of commutator is very convenient to use.

Plug type Commutator. (Fig. 146 B). The battery is connected to terminals which are diagonally opposite each other and the galvanometer, etc. are put across the other terminals. Plugs should never be inserted in adjacent holes but be put in diagonally opposite holes.

Pohl's Commutator. (Fig. 146 C.) The wires from battery are connected at A and B and the galvanometer circuit completed through either C and D or E and F. The terminals

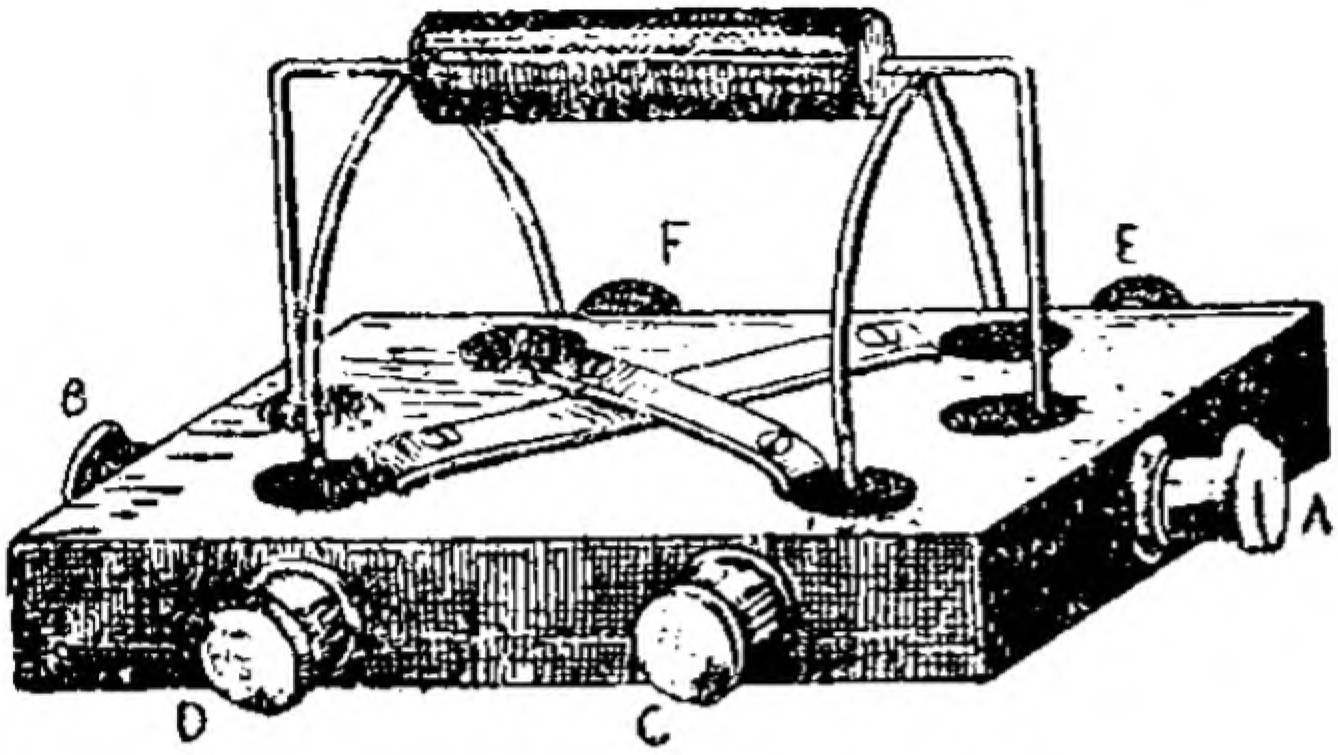


Fig.146 C.

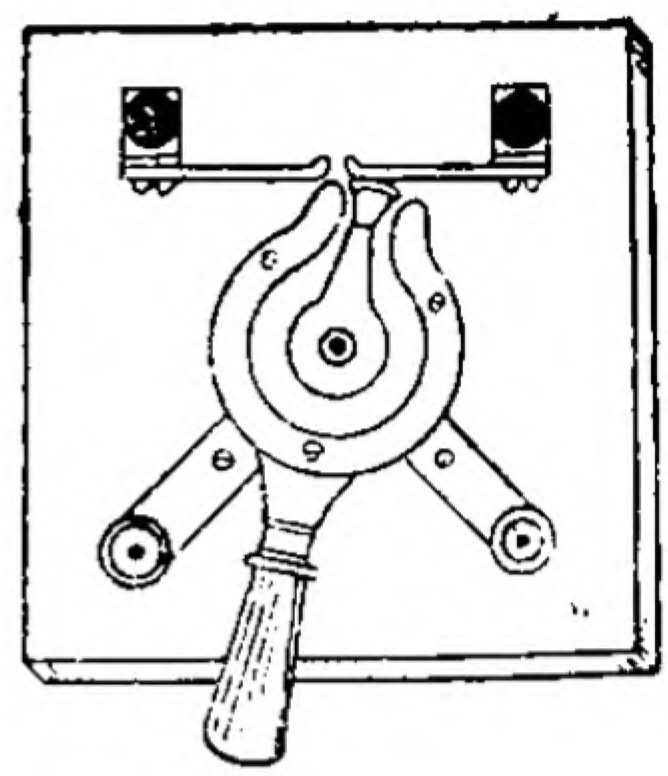


Fig. 146 D.

of the rocking part P which is a **six-legged spider** should be well under mercury. Care should be taken that the wires crossing each other do not touch.

Bertin's commutator. (Fig. 146 D) is now rarely used.

CHAPTER XXX

ARRANGEMENT OF BELLS, TELEGRAPHS AND TELEPHONES

Arrangement of Bells

Electric Bell-push. Unscrew the top of the bell-push and examine it. There is spring which on being depressed by the ivory button comes in contact with a metal strip under it and closes the electric circuit. It is nothing but a simple press key.

Experiment. 94.—**Arrange an electric bell so that it begins to ring when the button is pushed.**

Apparatus. Electric bell, push button, Leclanche cell, connecting wires.

Method. Arrange the push button and the bell in series with the cell as in Fig. 147. On pressing the button the bell will ring, if it does not, adjust the screw H, till the spring S touches the armature A and a tiny spark is seen to pass.

Trace the path of the current, when the button is pressed. The current enters at the terminal T, goes to the screw H and if the end of the spring S is touching the armature, it passes into the coils of the electromagnet through the armature A and goes to the terminal T and thence through the button back to the cell. The soft iron within the coils attracts the armature to itself and the hammer is carried with it and strikes against the gong G. When the armature is attracted the contact between it and the spring is broken and the current stops. The electromagnet loses its magnetism and the armature flies back taking the hammer with it and again contact is established.

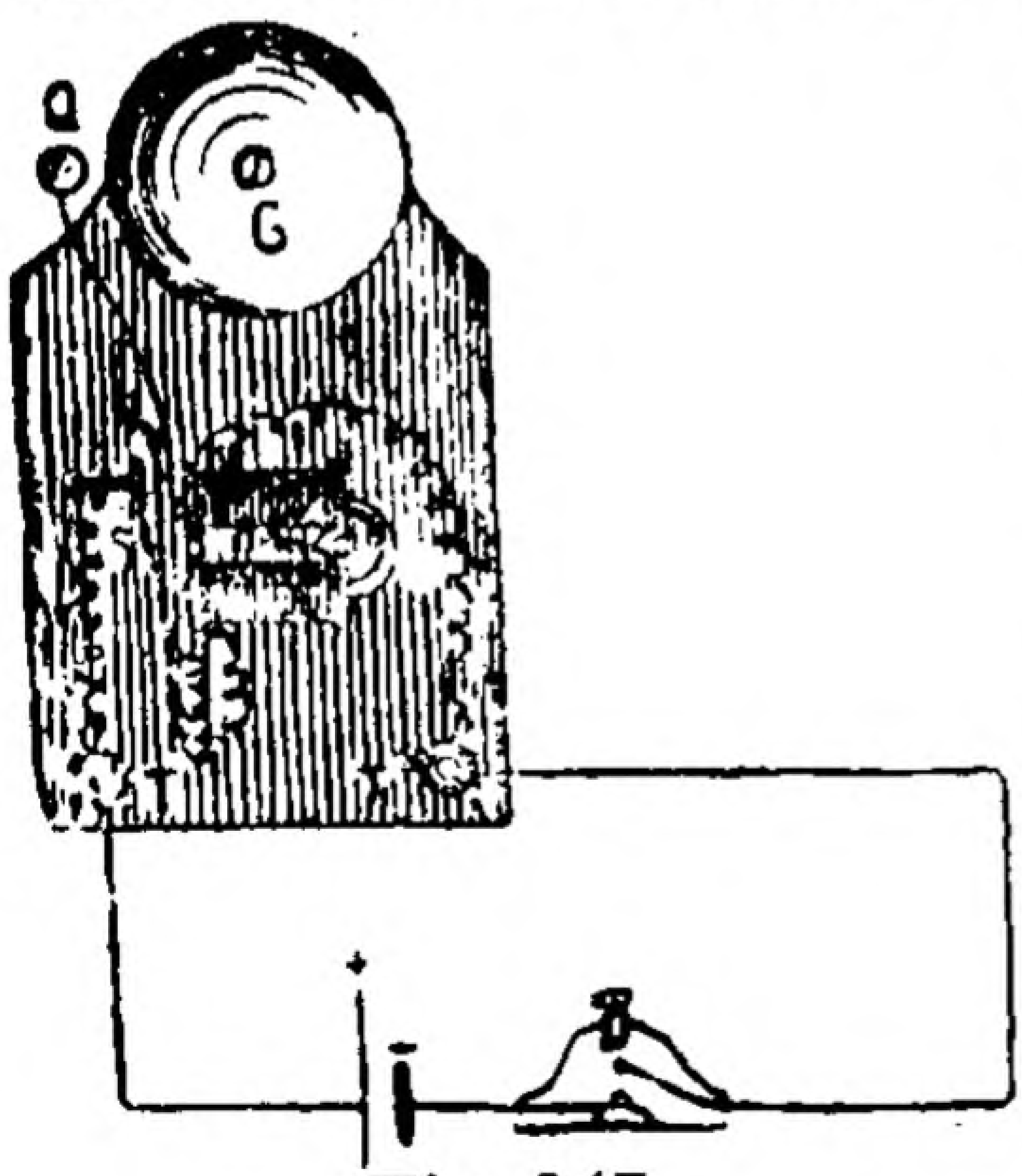


Fig. 147.

Ringing of bells from the mains.—Bells can be worked with mains but in this case they have to be suitably wound. If an ordinary bell is to be used with the mains one or more electric bulbs should be put in series with the bell.

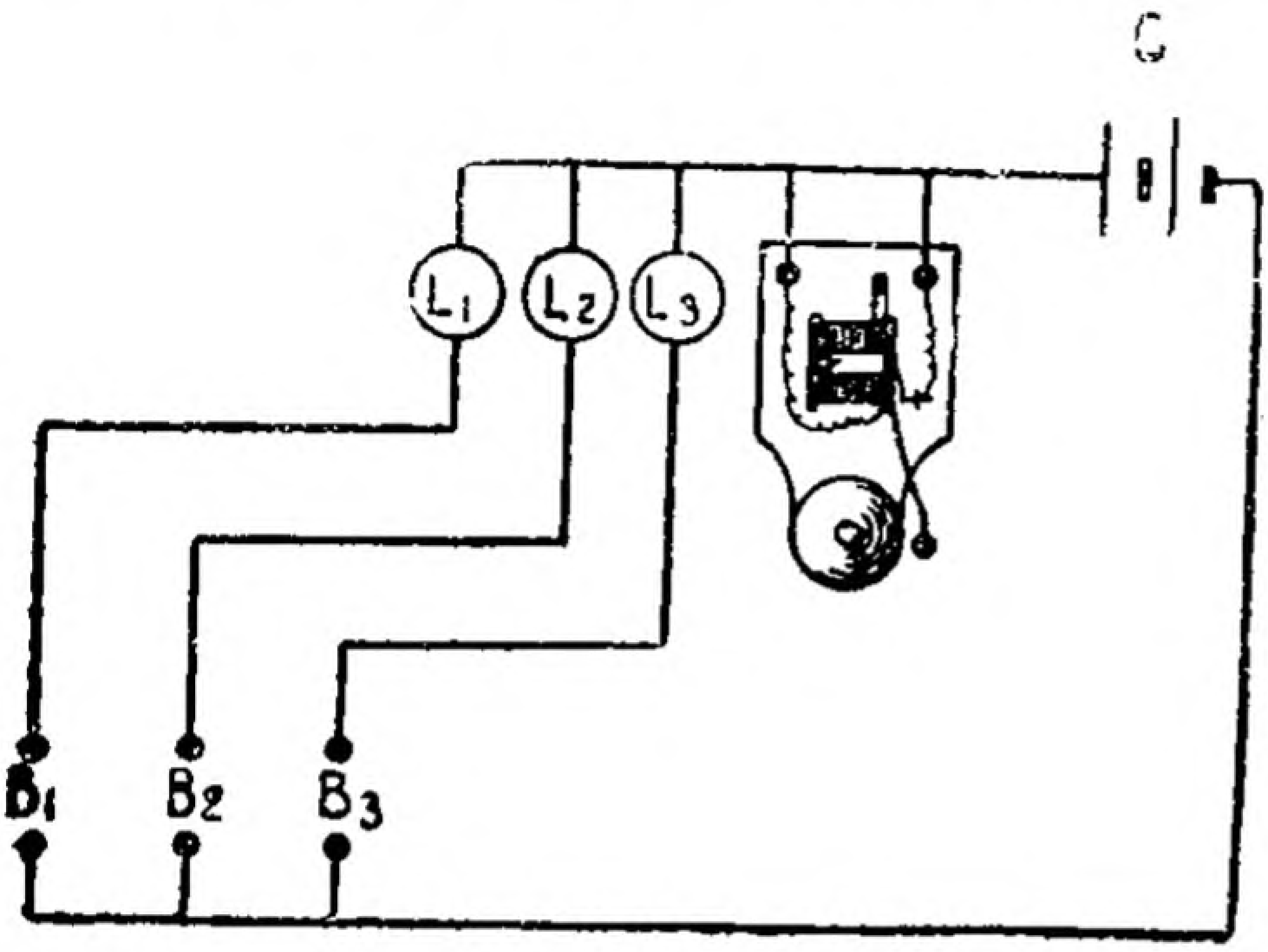


Fig. 148.

Exercise.—*Put a bell so that it can be worked from the same cell from the main gate, dining room and drawing room of a house, the rooms being indicated by differently coloured electric bulbs.* Arrange the various parts as shown in Fig. 148. B_1, B_2, B_3 are the push buttons placed at the three places and L_1, L_2, L_3, are the electric bulbs corresponding to them. Trace the path of the current and see how the circurit is completed.

Experiment 95.—**Arrange three bells near a kitchen so that these can be rung from the front door, dining room and drawing room.** Fig. 149 shows the way how the three bells can be arranged.

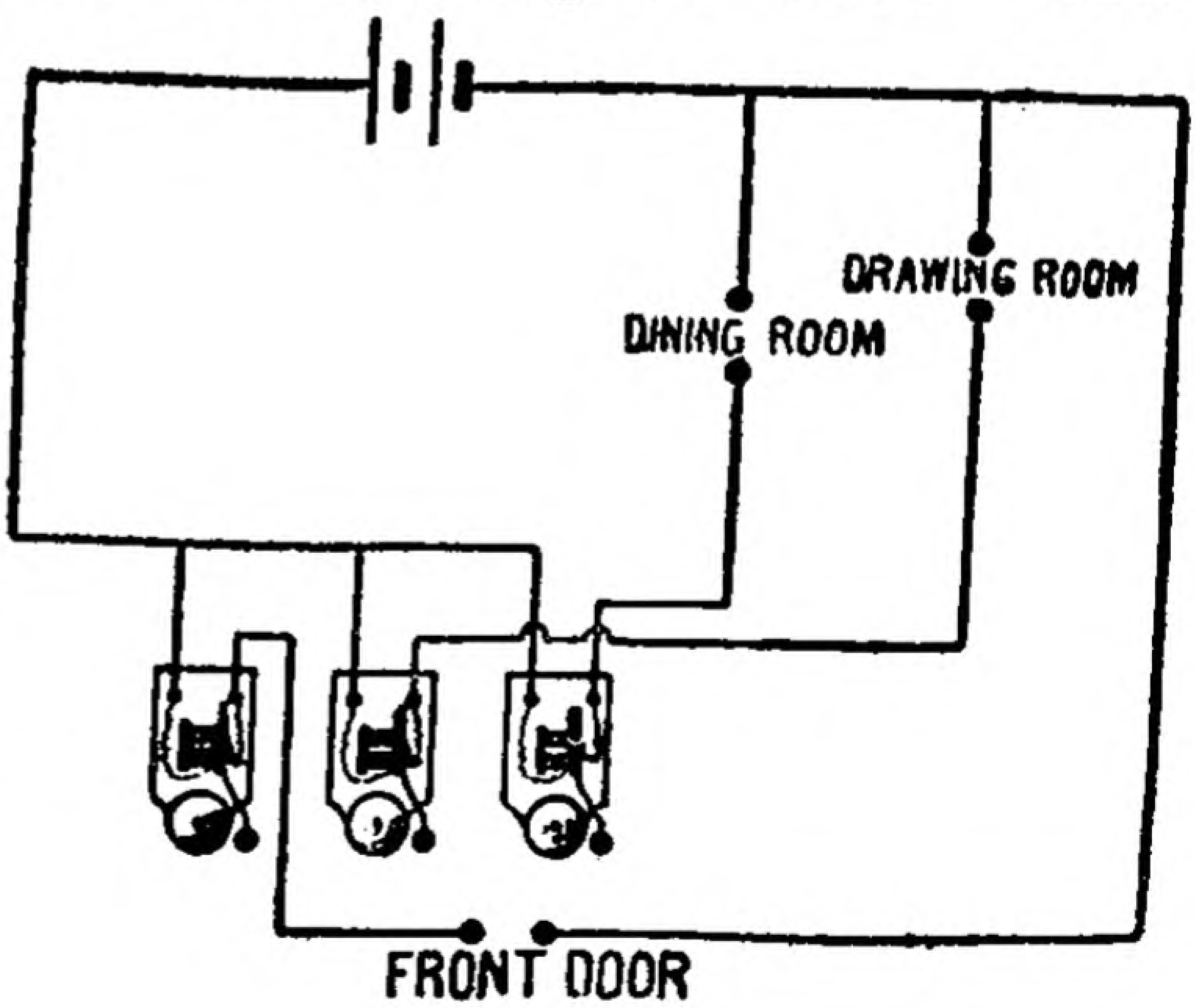


Fig. 149.

TELEGRAPH CIRCUIT

Morse Key. It is a sort of press key (Fig. 150) by means of which the sender transmits the messages. The key is

fitted with a lever and three brass studs. In the normal position, *i.e.*, when the key is not depressed the connection

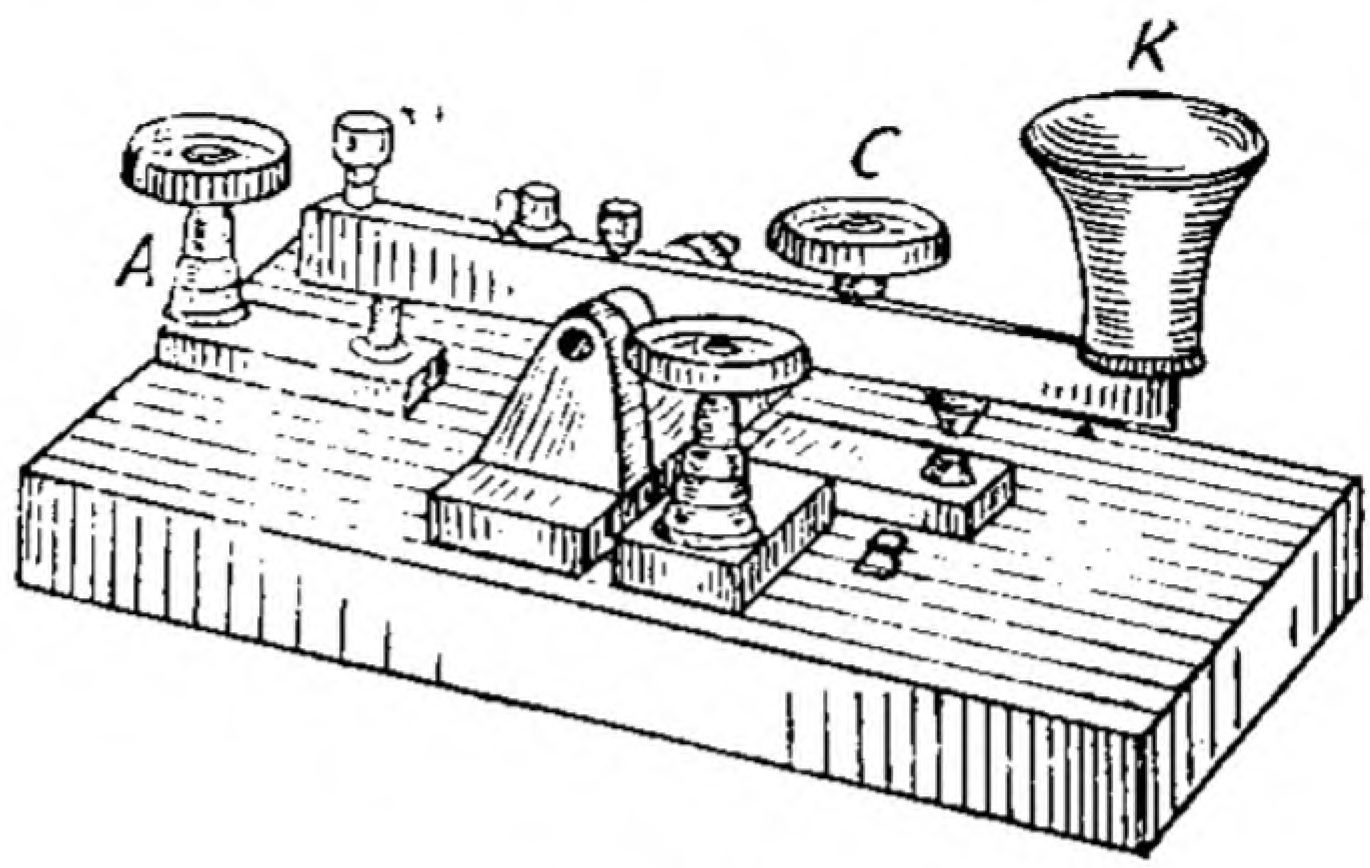


Fig. 150.

is made by the lever between C and A, while on pressing down the knob K, contact is established between C and B. The terminals A, B and C are kept connected with the recorder, battery and line wire respectively.

Sounder. (Fig. 151). It consists of an electromagnet with the heavy armature pivoted over its two poles. One end of the armature is held down by the springs while the other end is free to move through a small distance. When the current passes through the electro-magnet it

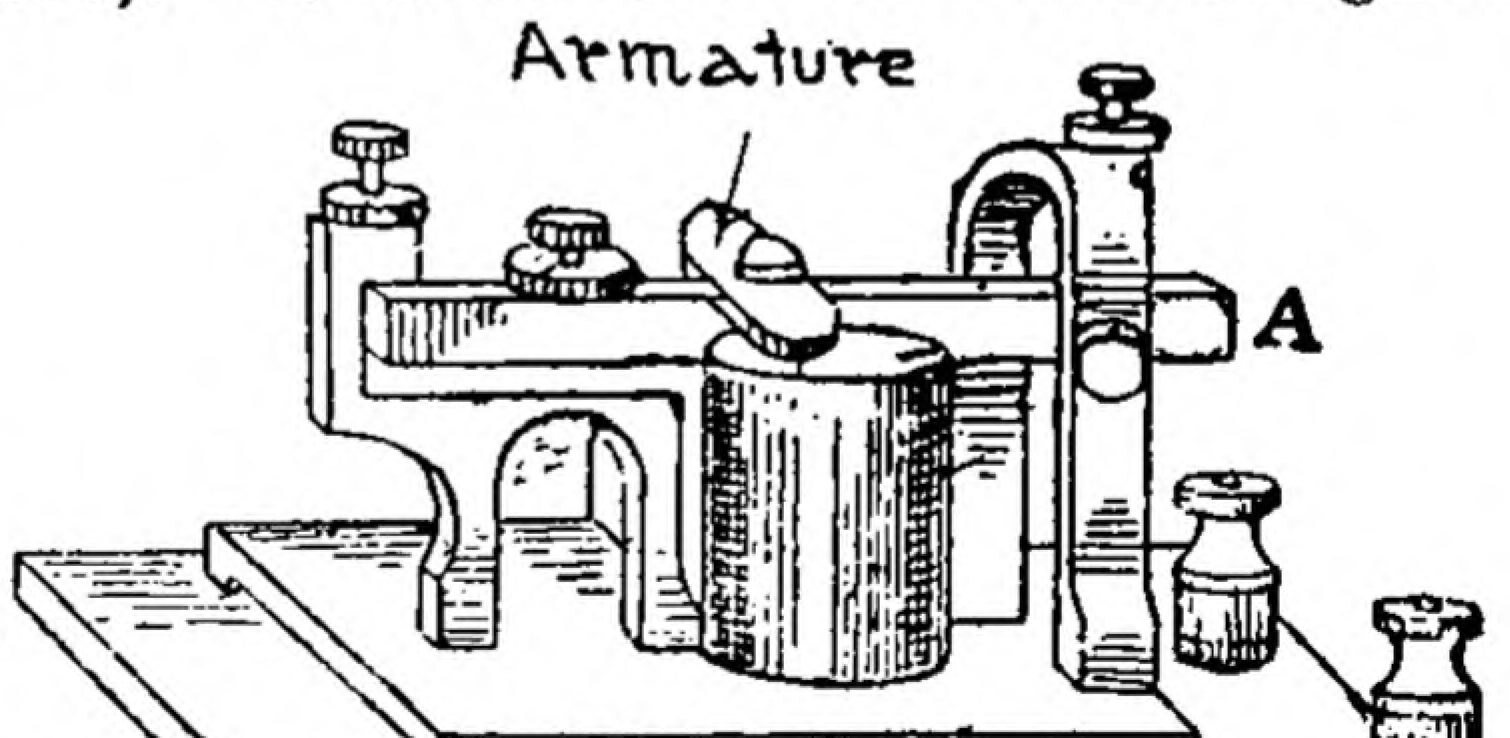


Fig. 151.

attracts the armature down and it strikes against the lower stop. When the current stops, the spring pulls it up and it now strikes against the upper stop. The time elapsing between the two sounds is short or long according to the duration of the current and it correspounds to the dots and dashes of the Morse Alphabet.

Relay. As the current coming over the line wire from a great distance becomes weak and is not sufficiently strong to work a recorder, a relay, (Fig. 152) is used. It is merely a circuit closer and consists of an electro-magnet made of very large number of turns of a very fine wire and has got a delicately poised armature which when attracted closes a local circuit of which a sounder and a local battery form part. The electromagnet of the relay is connected to the line through the binding screws A and the other terminals, are for the local circuit.

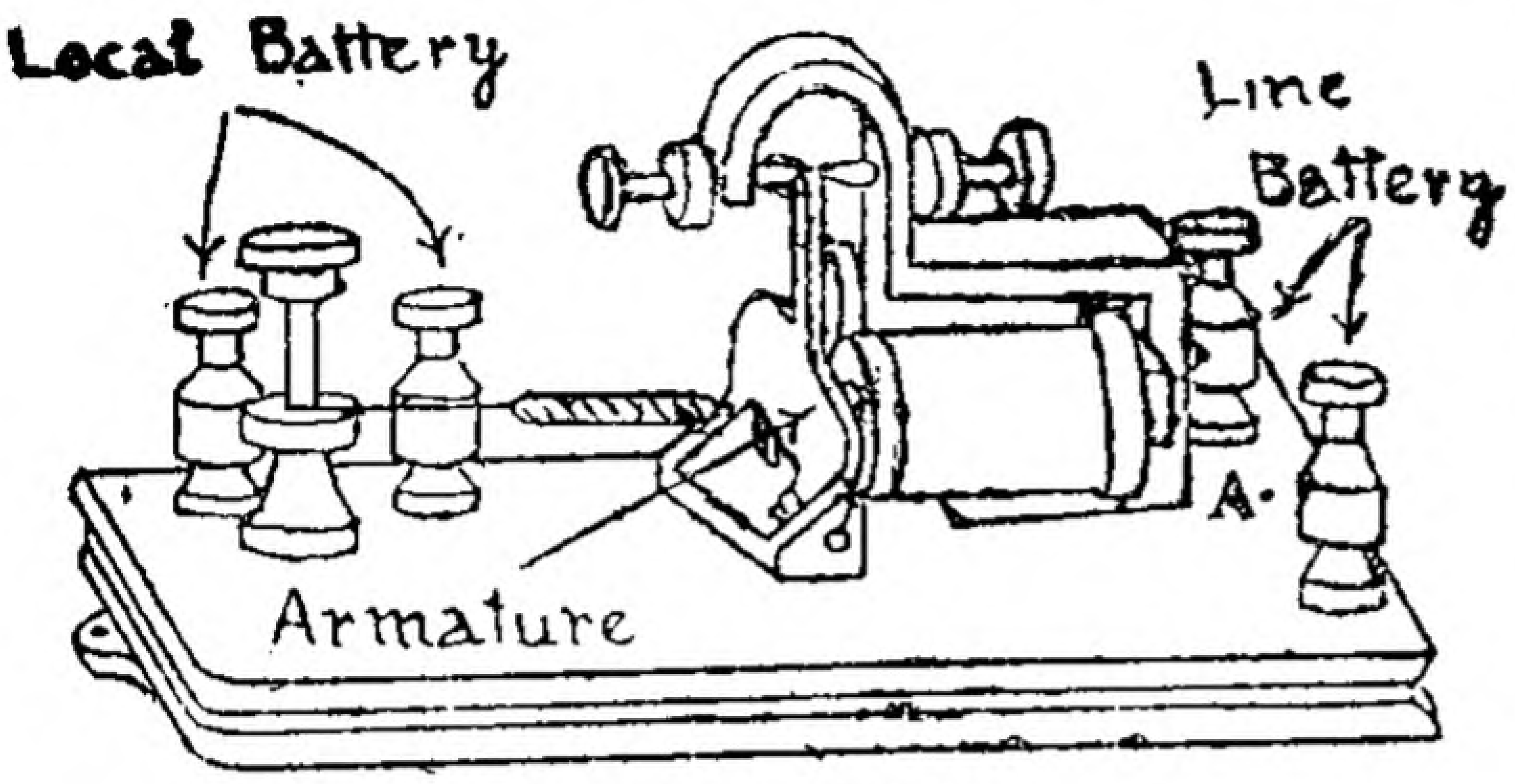


Fig. 152.

Experiment 96.—**Arrange a simple telegraph, sending and receiving both ways.**

Apparatus. Four Leclanche cells, or two accumulators, two Morse keys, two sounders or buzzers, long copper wire.

Method. Connect the various parts as shown in the Fig. 153. Use two Leclanche cells in series on the both sides. Connect the + pole with that terminal of Morse key which is under the knob and the line wire with the middle terminal. Gas pipe on the table may be used as return wire or earth. Rub with sand paper and thoroughly clean that part of the gas pipe to which the wire from the negative pole of the battery is to come. For connecting with the pipe, use four or five turns of bare wire and see that the connection is tight. The third terminal of the Morse Key should be connected to the sounder and the other terminal of the sounder to the gas pipe. The second pole of the battery should also be connected to the gas pipe. Send and receive from both sides and carefully trace the path of the current. Instead of the sounder, a buzzer can be used. If the sounder does not work, adjust the screw and

bring the armature a little closer. The experiment may be tried first with one cell on each side, and if the current

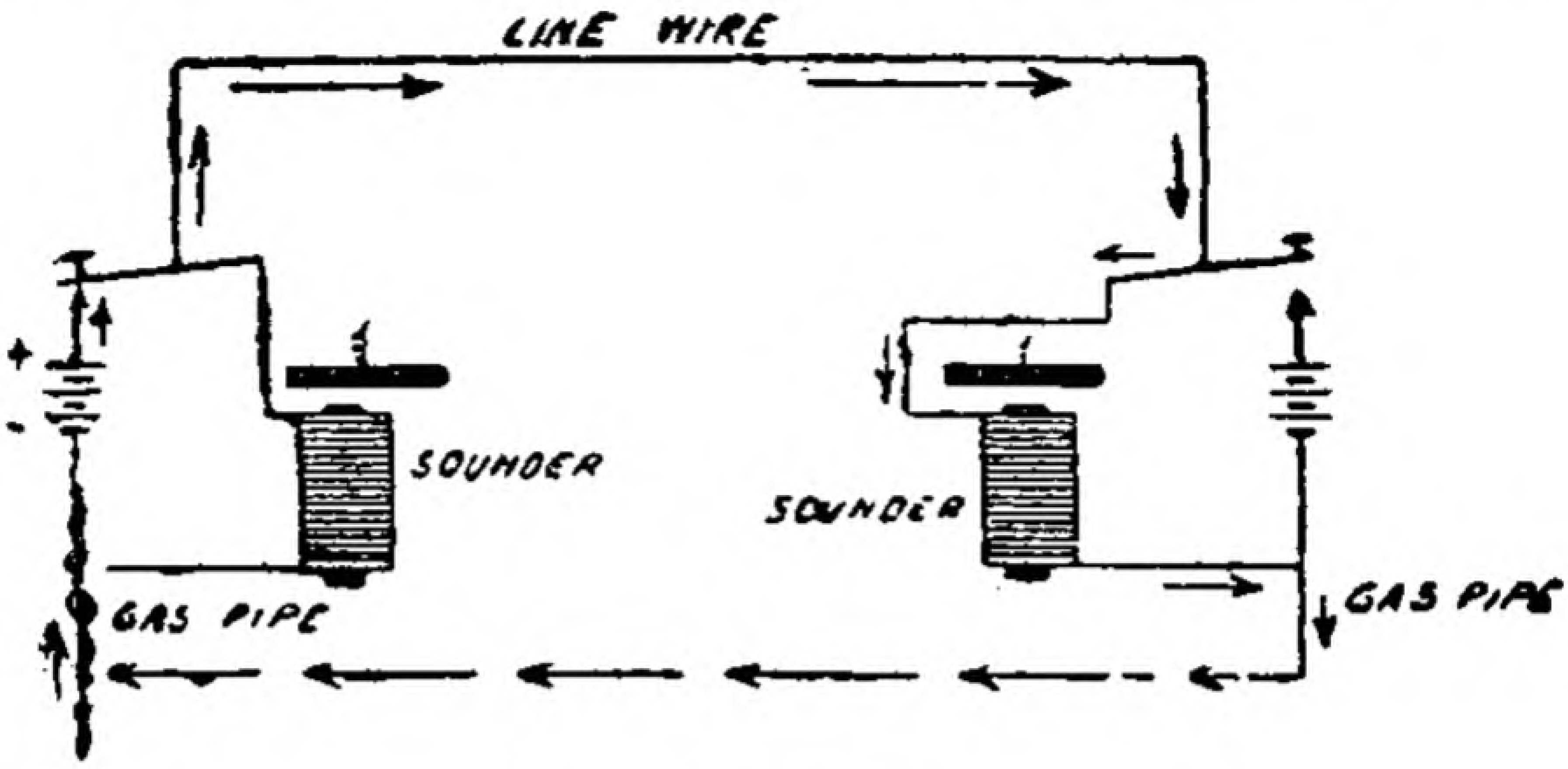


Fig. 153.

is found to be weak then two cells may be used.

Experiment 97.—**Arrange a simple telegraph sending and receiving both ways using a relay and local battery.**

Apparatus. Cells, two relays, two sounders, two press keys, long copper wire.

Method. Arrange the apparatus as thown in the Fig. 154. For return wire or earth use the gas pipe as in the last experiment. Work from both sides and carefully follow

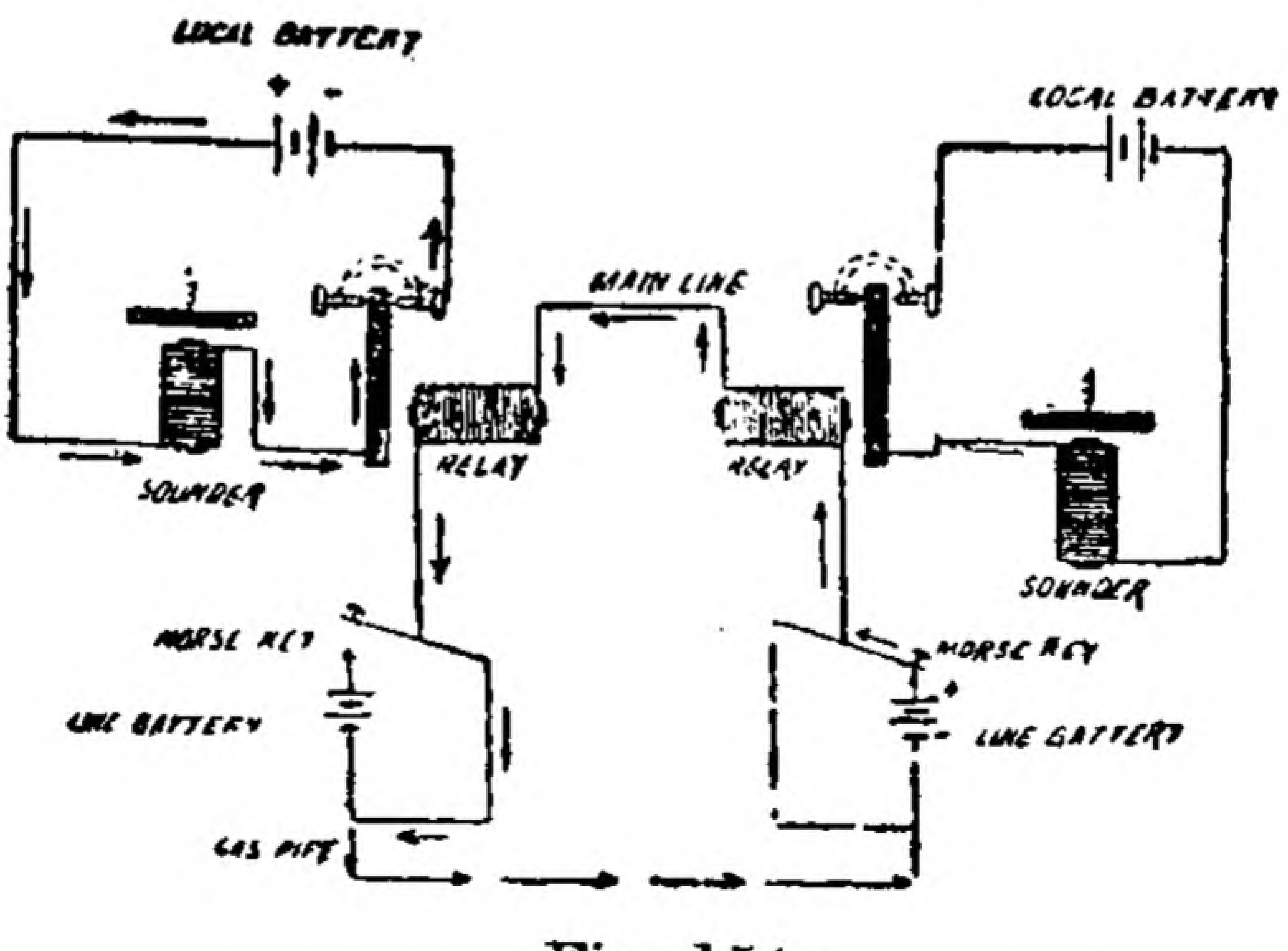


Fig. 154.
Telegraph circuit with relay and local battery.

the path of the current and see how the armature of the

relay closes the circuit of the local battery. In case the sounder and the relay do not work satisfactorily adjust their screws and bring their amatures closer.

Telephones. Before we study the actual arrangement of a telephone circuit, let us first study the two principal parts of a telephone namely the transmitter and the receiver.

Transmitter. A modern transmitter (Fig. 155), consists of a small chamber B fitted with particles of granular carbon. The front of this chamber is made of a carbon plate attached to a vibrating diaphragm. It is connected to a terminal of a battery in series with the primary coil of a small transformer or induction coil. The back of the chamber consists of a fixed carbon plate wich is connected to the other primary terminal of the transformer. The sides of the chamber are made of some insulating material, the diaphragm is held round its outer edges by the containing case.

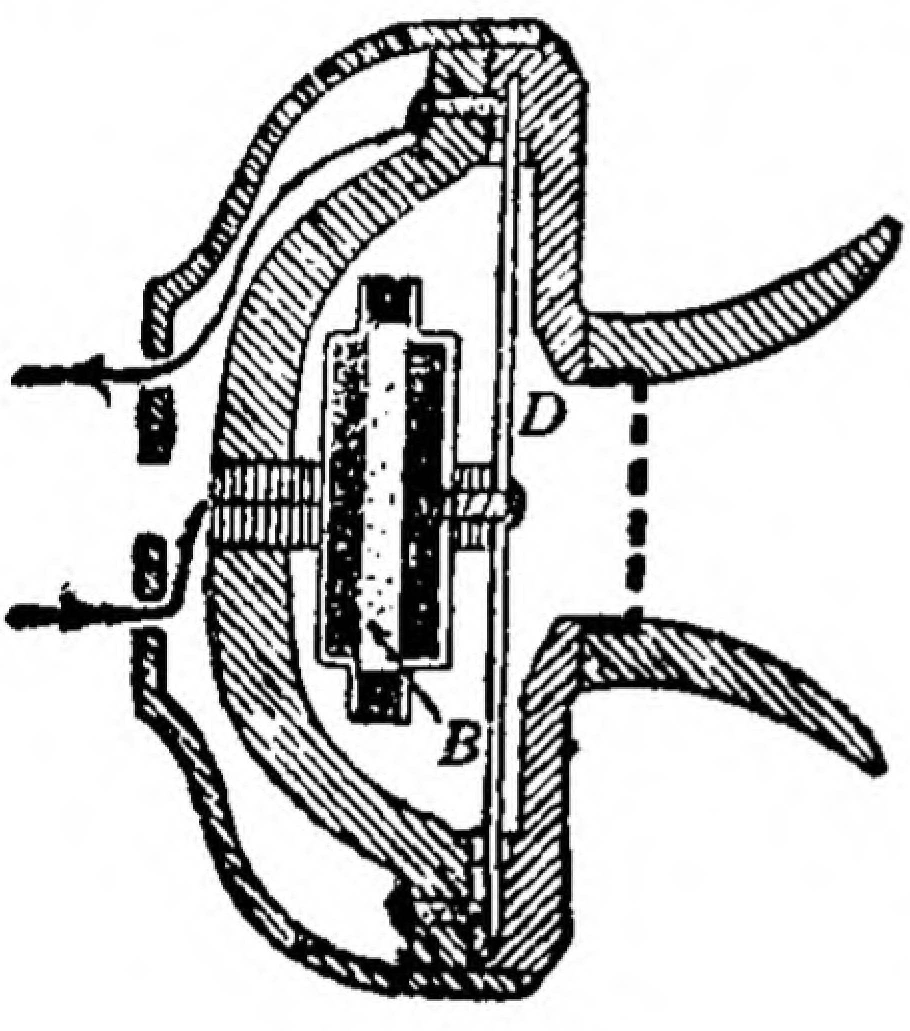


Fig. 155.

When we speak in front of the diaphragm, alternately waves of compression and rarefaction are set up and are through air applied to the diaphragm which presses the carbon particles with rapidly varying degree. This causes corresponding variation in the resistance offered by the particles, a varying current thus traverses through the primary of the transformer and induces corresponding currents at higher voltage in the secondary. As the secondary winding is connected with the line wire, these currents pass over the line and affect the receiver at the other end.

Receiver. A modern telephone receiver is shown in Fig. 156. It consists of a U-shaped piece of steel which is permanently magnetised. Two coils B B of very fine insulating wire are wound in opposite direction round the two poles and are put in series with each other. In the coils are placed cores of soft iron. The diaphragm E is placed in front of the two poles and almost touches the ends of the magnet. G is the ear-piece. When current

from the line passes round the coils it either strengthens the field or weakens it, the diaphragm is thus attracted

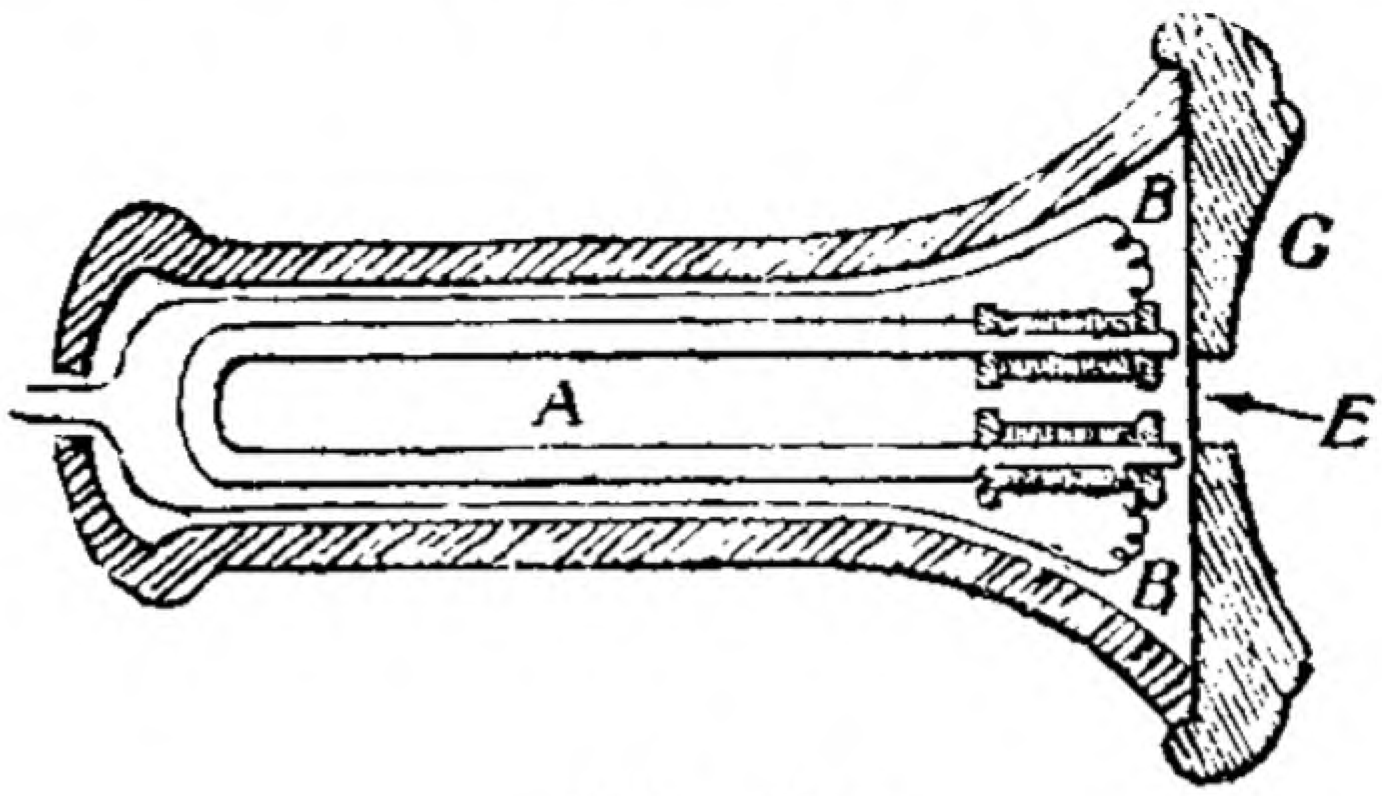


Fig. 156.

either more strongly or weakly. The variation in the magnetic pull on the diaphragm sets it in rapid vibration and the diaphragm produces sound waves exactly like those which had fallen on the diaphragm of the transmitter.

To study the receiver and transmitter of a telephone.

Open carefully the receiver and see the U-shaped magnet coils round the poles and the diaphragm. Sketch the instrument in your note book. Under the instructions of the teacher open the transmitter and study its parts. Trace the path of the current from the microphone to the primary windings of the transformer coil. Draw the sketch on your note book.

If you have got a hand set—combined receiver and transmitter—carefully open and study that also.

Experiment 98. **To set up a two way telephone without bells (local battery system.)**

Apparatus.—Four cells or two accumulators, two simple plug keys, two microphones, two receivers, two transformers

Arrange the apparatus as shown in the Fig. 157.

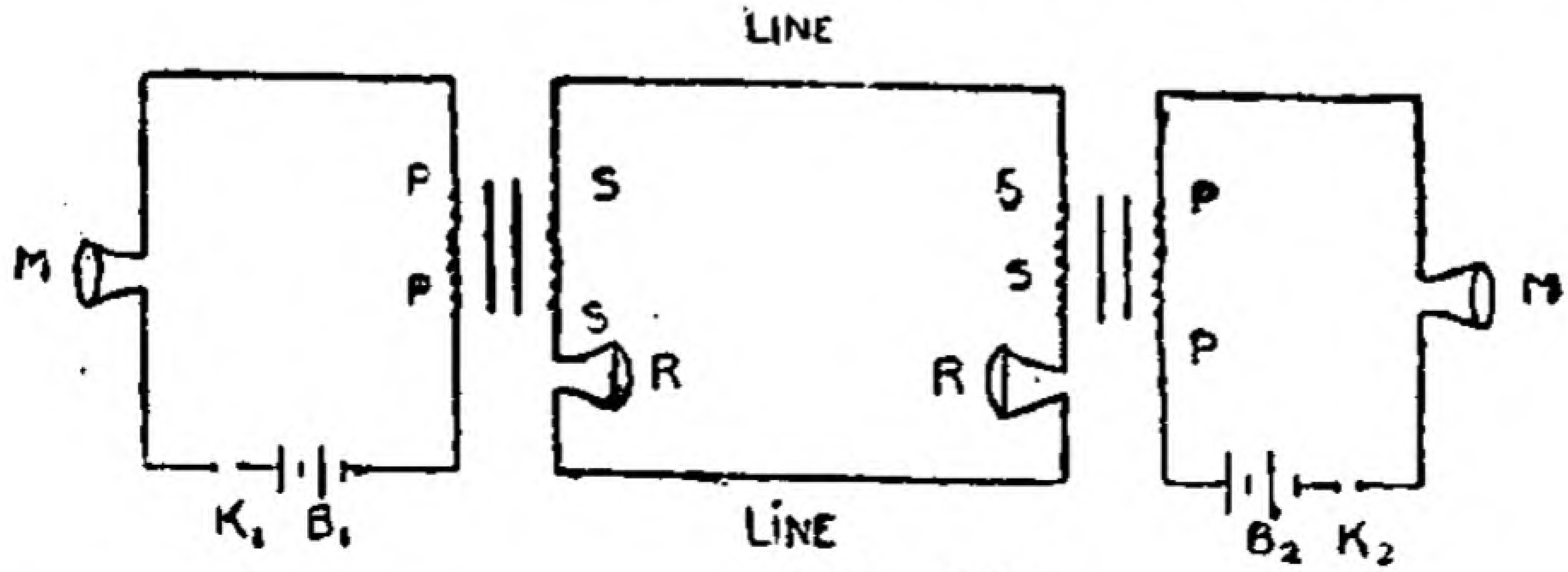


Fig. 157.

K_1, K_2 are plug keys, PP, SS, are primary and secondary terminals of the transformers. Use two cells or one accumulator on each side. Note that one end of the microphone M is connected to one end of the primary PP, the other end of primary is connected to one end of the battery, the second end of the battery is connected to the second end of the microphone through a key, *i. e.*, the primary, microphone and battery are all connected in series through a key. Similarly the two secondaries, the two receivers and the line wire are also connected in series.

Insert plugs at K_1 and K_2. Hold your microphone near your mouth and receiver near your ear. The microphone and receiver at the other station also should be held similarly. Speak in front of your microphone and hear through the receiver.

Precautions.—1. Connections should be tight.

2. Ends of connecting wire should be cleaned.

3. Keys in battery circuit must be put.

4. When not talking remove the plugs.

5. If sounds in the receiver be feeble increase the number of cells.

NOTE.—As the two receivers, the line wire and the secondaries are all joined in series these may offer a great resistance to the current flowing in and the sound in the receiver may become feeble. If so, put one more cell in the microphone circuit.

Experiment 99.—**To set up a two way telephone with bells (Local battery system).**

Apparatus.—8 cells or 4 accumulators, two simple plug keys, two two way keys, two receivers, two transformers, two bells, connecting wires.

Method.—Arrange the apparatus as shown in the Fig. 158.

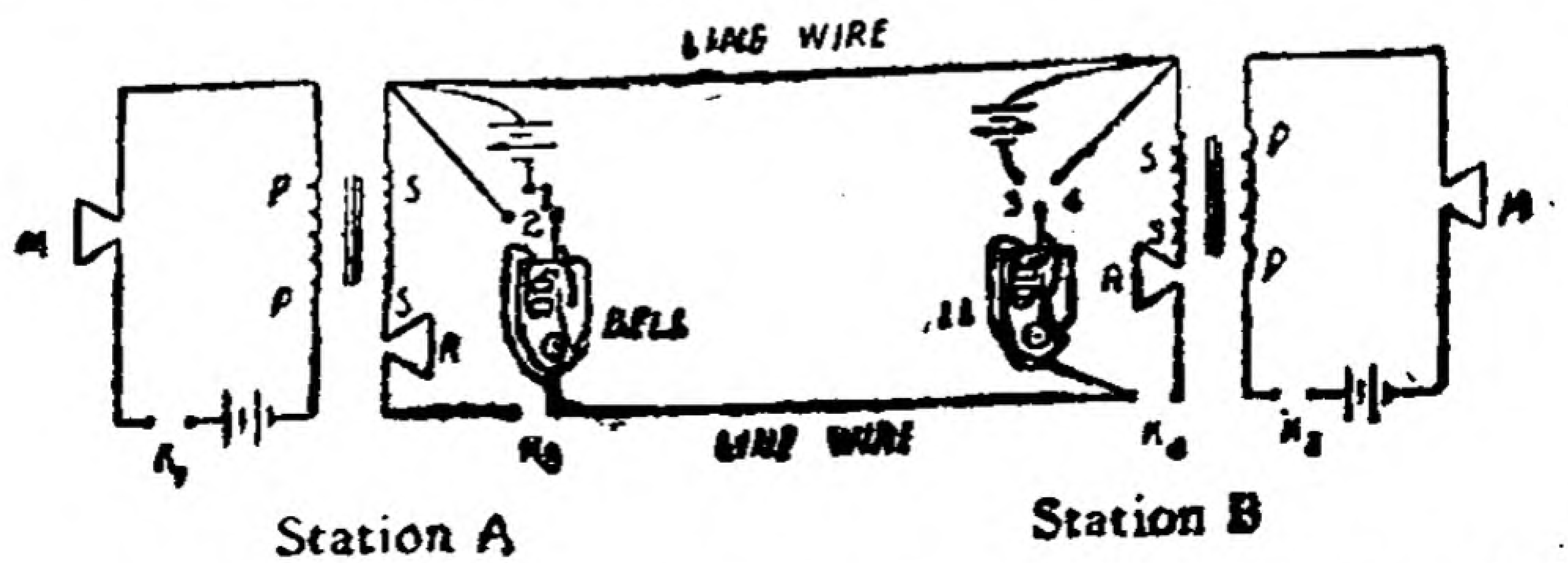


Fig. 158

The primary winding PP of the transformer, the microphone M and the battery should be connected in series through a key as shown in the figure 158. Note carefully that one end of the microphone is to be joined to the one end of the primary, the other end of the primary is to be joined to one end of the battery. The second end of the microphone is to be joined to the other end of the battery through a key.

The line wire, the two receivers and the secondaries of the transformers at the two stations are also to be connected in series; the bells and their cells are arranged as shown in the figure.

To ring bells from the station A:—

In the two way key of the station A, insert the plug in the position (1) and also insert a plug in the two way key of the station B at the position marked 4, the bells of both the stations will be in circuit and will ring simultaneously. Similarly to ring the bells from the station B, the plugs should be removed from the positions 1 and 4 and should be in positions 2 and 3.

If bells do not ring then (*a*) adjust the screw of the spring of the bell; (*b*) put another cell in the bell and battery circuit.

In actual working the change of plugs is brought about automatically by means of jacks and switches.

For talking from either end—

(*a*) Remove the plugs from 1, 2, 3, 4 positions, *i.e.*, no plug should be inserted in the two-way keys.

(*b*) Insert plugs at K_1, K_2, K_3, K_4.

(c) Speak in front of the microphone M and hold the receiver R near your ear.

If the sound in the receiver be weak, put another cell in the microphone circuit.

Precautions.—1. Ends of connecting wires should be properly cleaned.

2. Connections should be tight.

3. The key must be inserted in the microphone circuit. As the line wire, the two receivers and the two secondaries are all joined in series, these will offer a great resistance to the current flowing in them; therefore the sound in the receiver may become weak. If this is so, put another cell in the microphone circuit.

CHAPTER XXXI

LIGHTING CIRCUITS

For lighting purposes, the current is generally supplied at 220 or 110 volts and if any one were to touch bare wires at these voltages, he will get a shock. It is, therefore, necessary that while working with city mains, one should be very careful.

For experiments in the laboratory on lighting circuits, it will be very convenient, if a number of lamps, switches, cut outs, fuse boxes, etc., are mounted on separate blocks of wood and terminals fixed on to them for connections as in Fig. 159. For the lamps, button holders may be used.

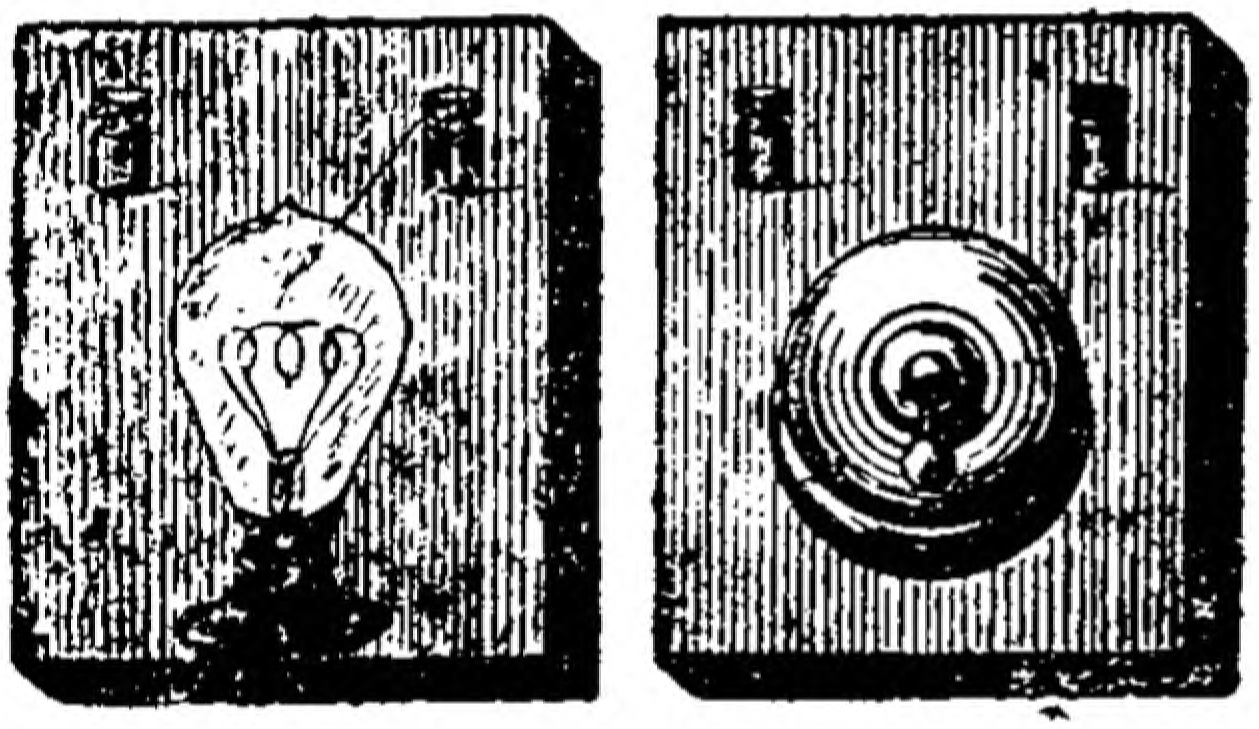


Fig. 159.

Such of the practical tables as those on which these be performed should be fitted with a wall plug and a porcelain fuse.

Where the city electric supply is not available, the experiments can be performed with accumulators if available or with dry cells and in this case lamps of proper voltage and suitable holders should be used. Before arranging the apparatus, read the following instructions carefully.

(1) Draw a diagram of connections and carefully trace the path of the current and see whether circuit is complete or not.

(2) Before connecting the various apparatus, see that the mains are off or if your practical table is fitted with a separate fuse and plug, the plug should be out of socket.

(3) The screw driver which you are going to use should have an insulated handle. Wooden handle is alright.

(4) When you bare the end of a wire, carefully clean it and see that it is tightly fixed.

(5) If any portion of a wire is bared for connections the bare portion should be carefully wrapped with insulating tape.

(6) As in lighting circuits the + and – wire run close together, care should be taken not to lay bare adjacent portions of the two wire. If for connections the wires have to be bared, choose two points (one on each wire) about 3 inches apart so that chances for short circuiting may be reduced to a minimum.

(7) Use a porcelain junction box at the points where the wires branch off.

(8) When the apparatus are arranged, before joining them with power, have the connections approved by your instructor.

Series arrangement. When the same current passes in succession through all the conductors, they are said to be arranged in series (Fig. 160). Here the conductors A, B and C having resistances R_1, R_2. and R_3 are in series. The current from the battery goes in succession through three conductors.

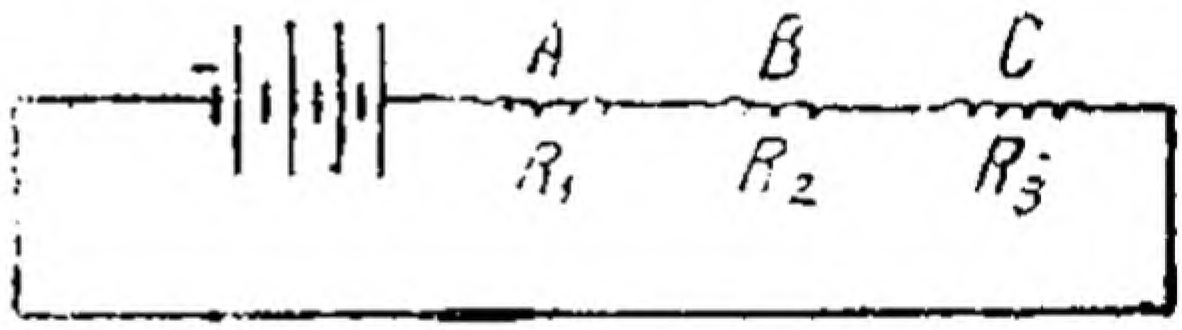


Fig. 160.

Total resistance of three conductors

$$R = R_1 + R_2 + R_3.$$

Parallel arrangement. Here the current C divides off in branches in the conductors, so that C $C_1+C_2+C_3$, and after traversing the conductors the various currents again unite. In this arrangement, if R is the total resistance of the conductors and R_1, R_2, R_3 individual resistances, then.

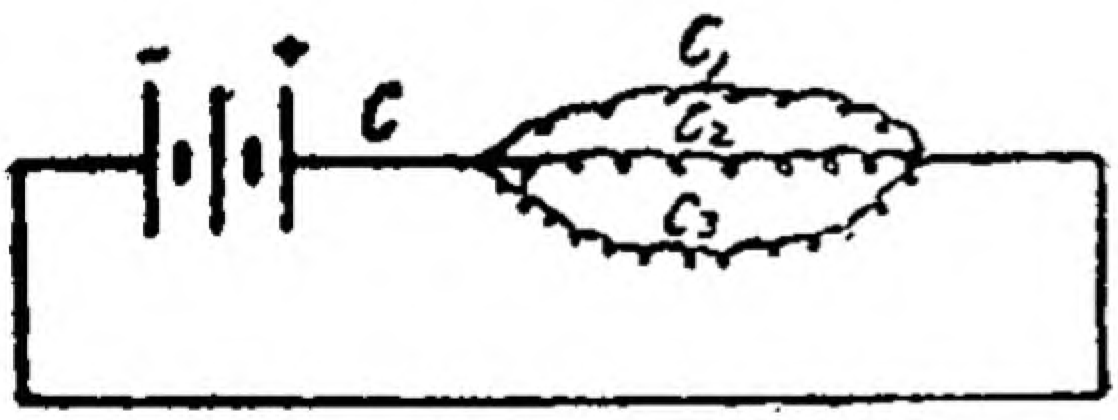


Fig. 161.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Experiment 100. **To study the relative advantages of connecting lamps in series and parallel.**

(This experiment can be performed with advantages by using dry cells or accumulators and lamps of corresponding voltage).

Apparatus :—Four dry cells (8 volts in aggregate) five lamps (2·5 volts each), 3 plug keys, connecting wires.

Method:—(*i*) **Series arrangement.** Arrange three cells and three lamps as in Fig. 162. Insert the plug and see that all the lamps are correctly lighted. Now either remove the plug or one of the lamps, none of the lamps will be now lighted. Next increase the number of

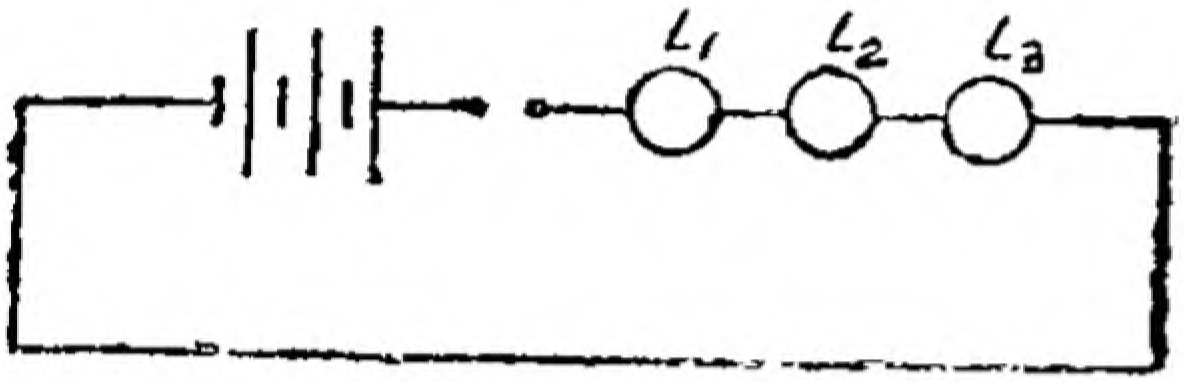


Fig. 162.

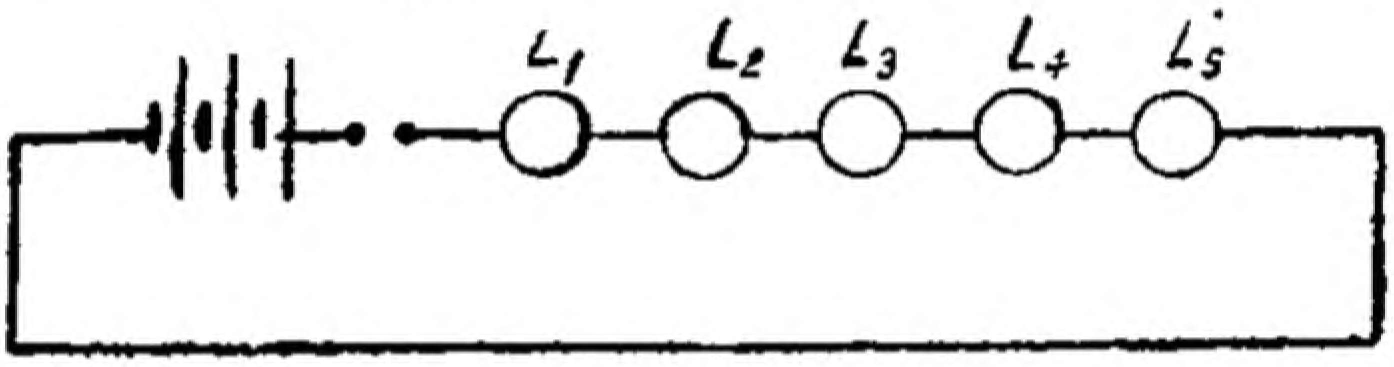


Fig. 163.

lamps to four, or better five (Fig. 163.) insert the plug all the lamps will be under-lighted.

(*ii*) **Parallel arrangement.** Arrange two cells and 3 lamps as shown in Fig. 164, using a plug key in the circuit of each lamp. Put 3 plugs in their places, all the three lamps will be found to be correctly lighted. Now remove one of the plugs, that lampof which the plug has been removed will be found to be put out, the other lamps will remain correctly lighted. Next remove the second plug, the third lamp will be found to be still lighted. Now disconnect one pole of the battery and insert in circuit a fourth plug and a lamp. Connect the battery and see that on inserting all the 4 plugs the lamps are still correctly lighted.

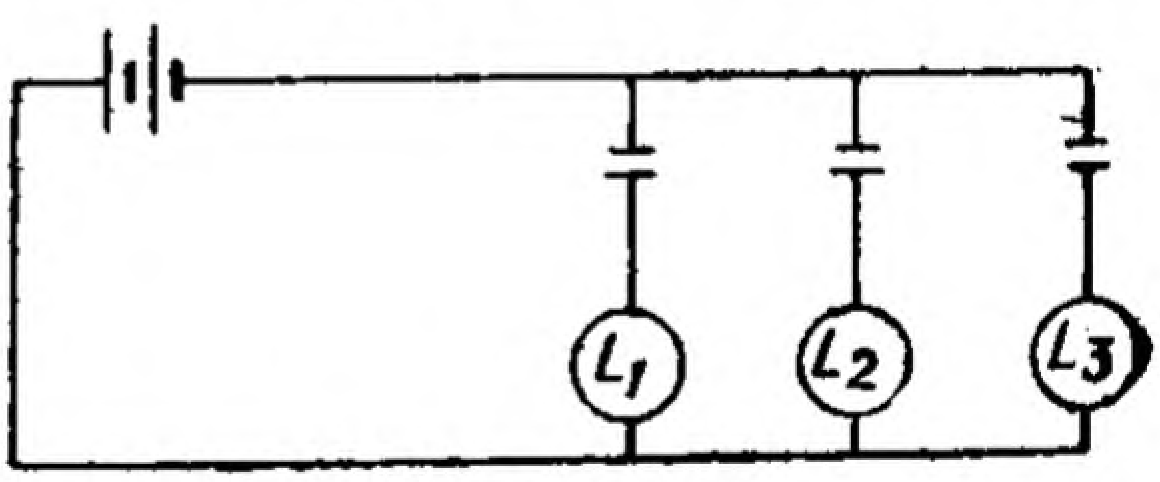


Fig. 164.

What is your conclusion from the experiments ? In series arrangement :—(*i*) The lamps are not independent, if one lamp is out of order, all will cease to give light. (*ii*) If the number were to be increased, the lamps become under-lighted. Why ?

In parallel arrangement :—The lamps are independent,

any one lamp can be switched on or off. The lamps are not under-lighted by moderately increasing their number.

Try the above experiment with incandescent lamps and current from the electric supply mains, but this should be done ofter performing the next two experiments.

Experiment 101 :—**Arrange an incandescent lamp controlled by a switch.**

Apparatus :—Lamp and switch mounted on blocks, insulated wires, (silk covered flexible wire can be used). Power (Battery or line).

Method. Make connections as shown in the Fig. 165. While connecting up, see that the power is off.

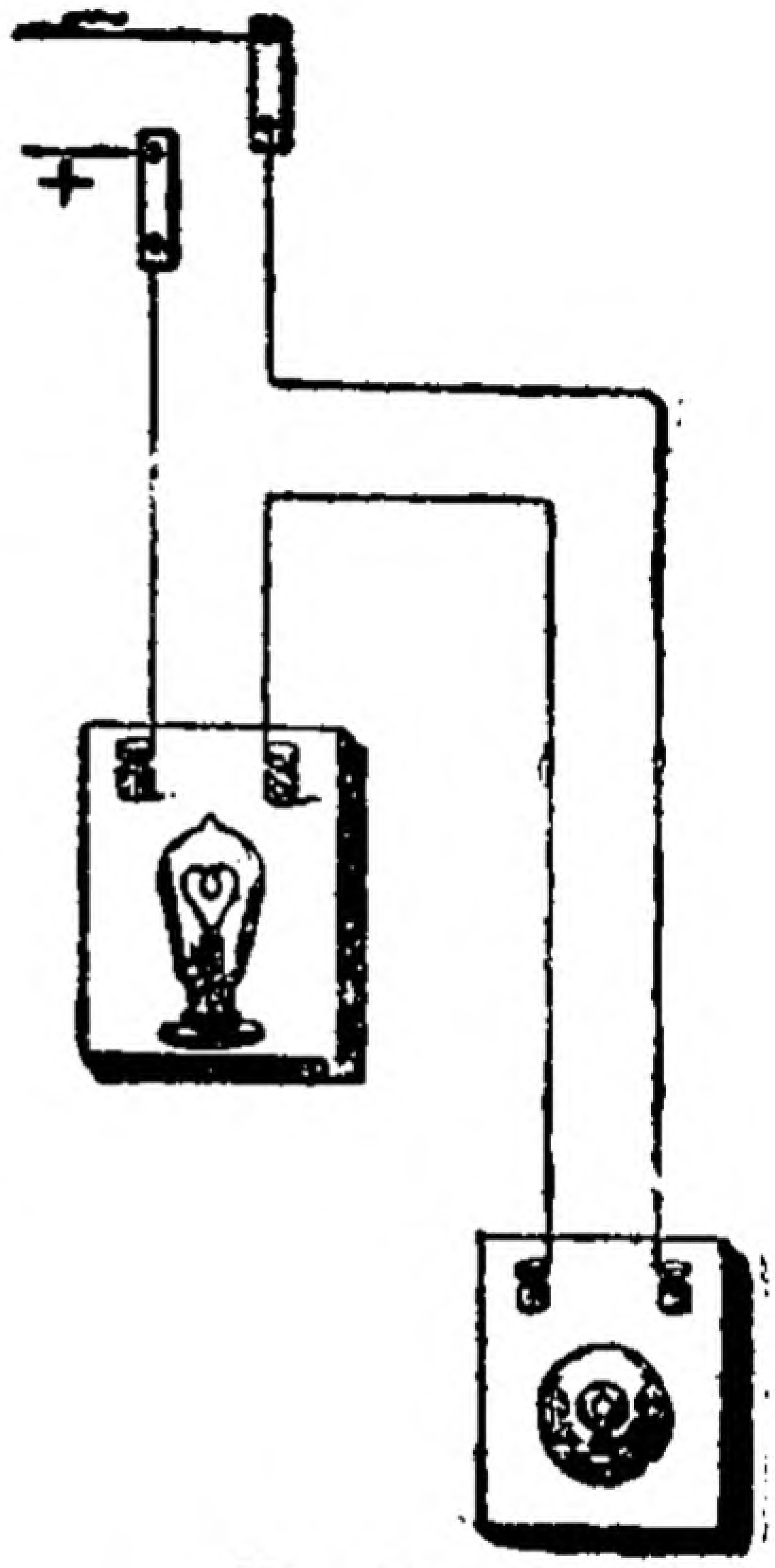


Fig.165.

Wiring is generally done on 'centre of distribution system.' This consists of running the mains to a distribution board from which submains after passing through fuses run to branch distribution boards. Form these branch distribution boards wiring is done for lights or other points. The greatest advantage of this system is that all the fuses are collected together at the centre and in case of trouble one knows to which fuse to go and moreover joints are also avoided. The companies generally recommend the wiring from distribution boards on small circuits carrying not more than 3 or 4 amperes. When this is done, fuses on the distribution board are ample to give protection.

Joints are the greatest source of trouble in wiring and therefore looping is generally done when more than one points are to be put.

Experiment 102.—**Arrange a circuit of three lamps and the three independent switches.**

Arrange as shown in Fig. 166.

Note :—The wire should not be cut, it shouid continuously run from one ceiling rose to the other, similarly the other wire from one switch to the other.

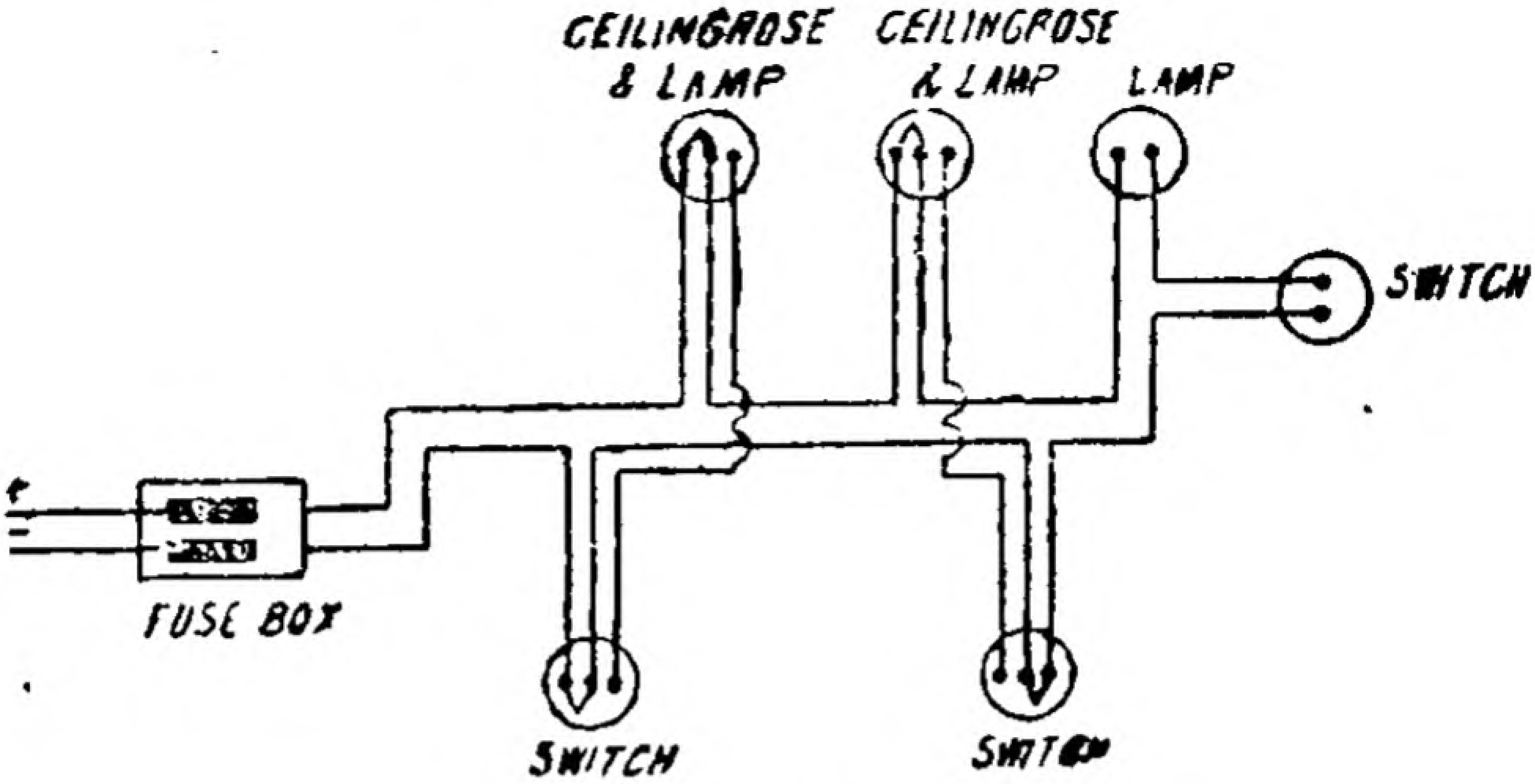


Fig. 166.

Circuits of 3 lighting points showing hooking in at switch and light.

Experiment 103. **Arrange two light points and one wall plug in different rooms with independent switches and two fuses on the distribution board.**

Arrangement of connection is shown in Fig. 167.

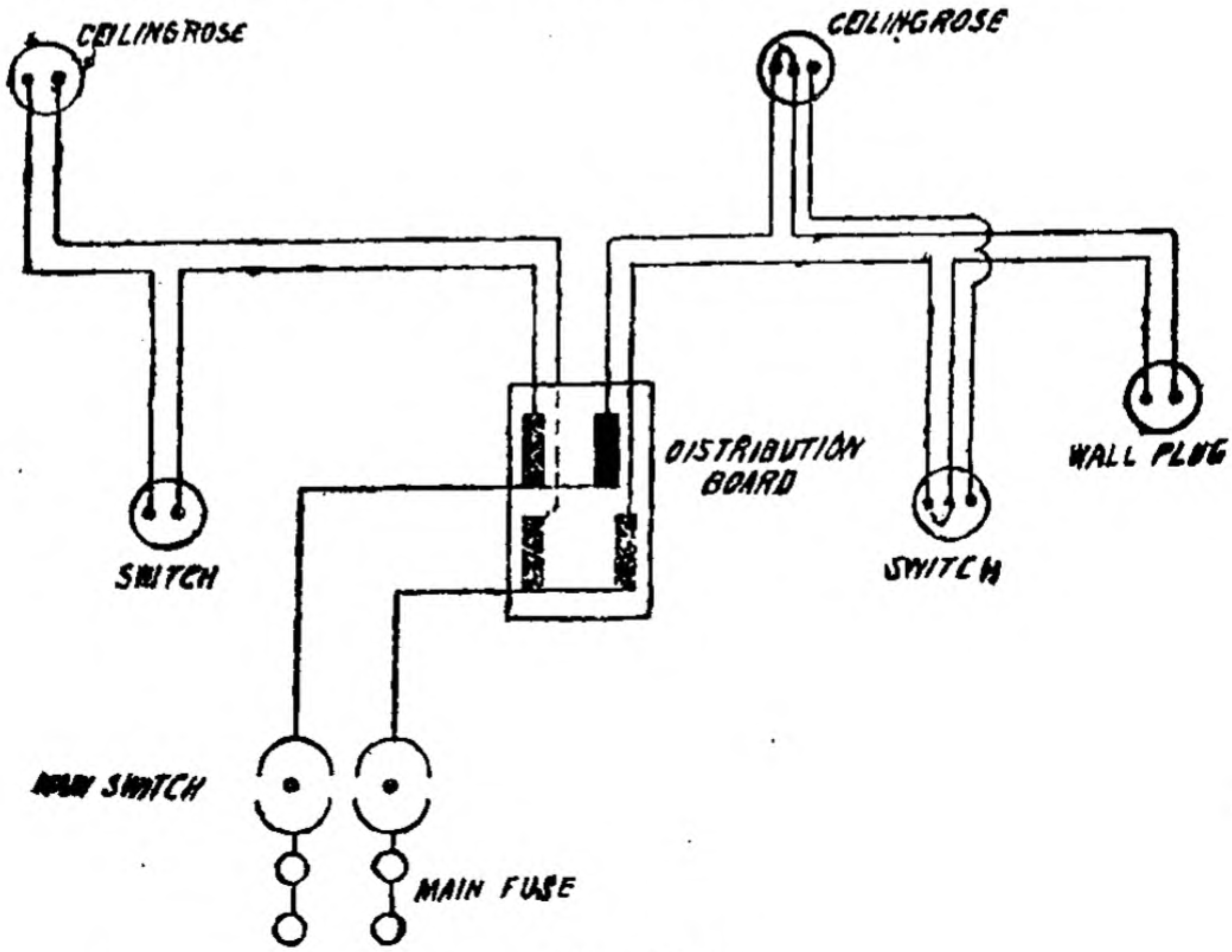


Fig. 167.

Special wiring.—Wiring to allow of lights or groups of lights being controlled from two or more points has led to multiplicity of two, three and four way switches. A common requirement is to switch off or on the light in a staircase from either end and to similarly control the light in a corridor.

Experiment 104. **Arrange a lamp in a staircase so that it can be put on and off at either end.**

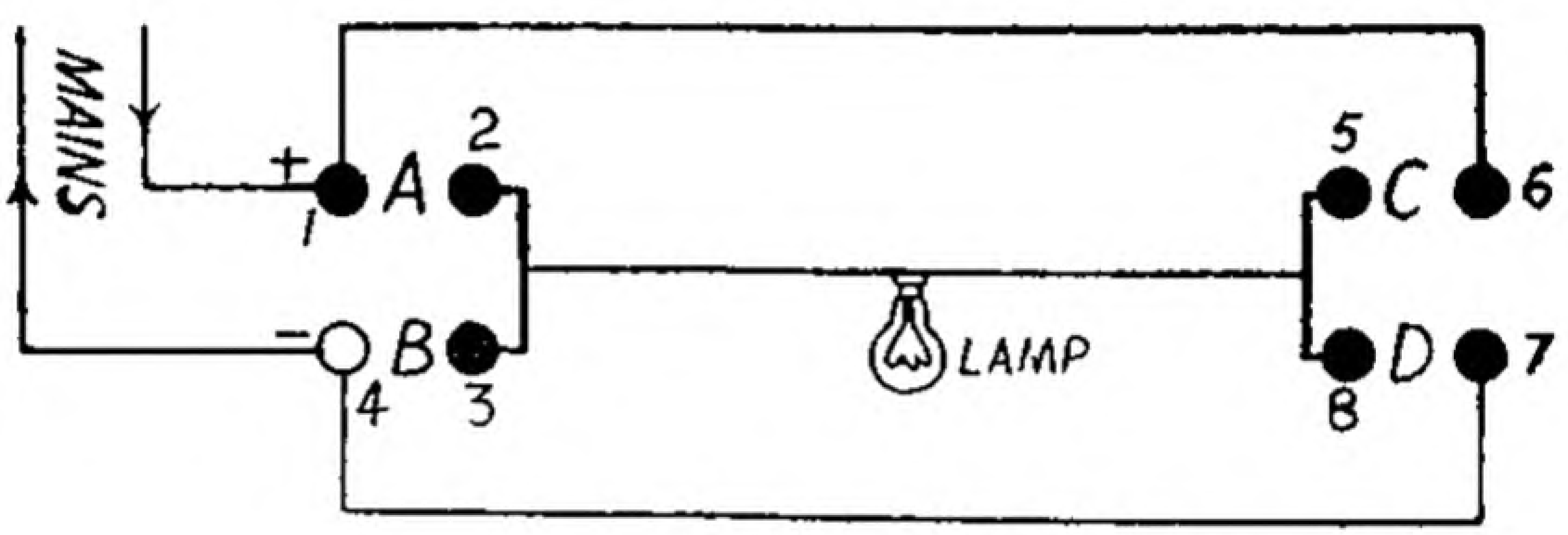


Fig. 168.

Arrangement of connections is shown in the above figure.

For this purpose ordinary type of a switch is useless and the double switch used has four terminals instead of two but two of these are joined together so that only three wires are to be connected to each switch. In the figure, the terminals 2 and 3 of one switch and 5 and 8 of the other switch are joined. The figure shows the usual way of making connections. It will be seen that the light point is to be connected to the terminals which are connected together *i. e.*, to 2, 3 and 5, 8. The other terminals are to be connected to the mains and with each other. By turning the knob of the switches the connection can be made either in the position A or B in the case of one switch and C or D in the case of other.

Trace the path of the current in different positions of the lever knob.

CHAPTER XXXII

CHARGE AND DISCHARGE OF A STORAGE BATTERY

Accumulators are in these days used extensively in automobiles for starting, lighting and ignition purposes and therefore some knowledge of their proper use has become an every day necessity. What we see on the outside is a box with lead strips and terminals.

Experiment 105.—**To demonstrate the principle of an accumulator.**

Apparatus :—Two lead plates, a rectangular glass cell, a tangent galvanometer, or an ammeter, two accumulators or two Bunsen cells, connectors for wires, three way key, a bell and a rheostat.

Method. Plates made from ordinary lead serve the purpose very well. In order to prevent them from coming in contact with each other when suspended they may be screwed to a $\frac{1}{2}$ inch thick strip of wood or better be suspended by means of hooks from two thick wires resting on the edge of the glass cell.

Connect the apparatus as shown in the Fig. 169. An *ammeter or better a tangent galvanometer G (50 turns)* and a rheostat R should be connected in series with the lead plates. The bell B should be in the branch circuit. The battery C (voltage more than two in no case less than 2) and the 3 way key should be connected as shown in the figure. Put dilute sulphuric acid (one of acid and 10 of water) in the glass cell, taking care that the wooden strip separating the two plates (if used) is not immersed in the acid.

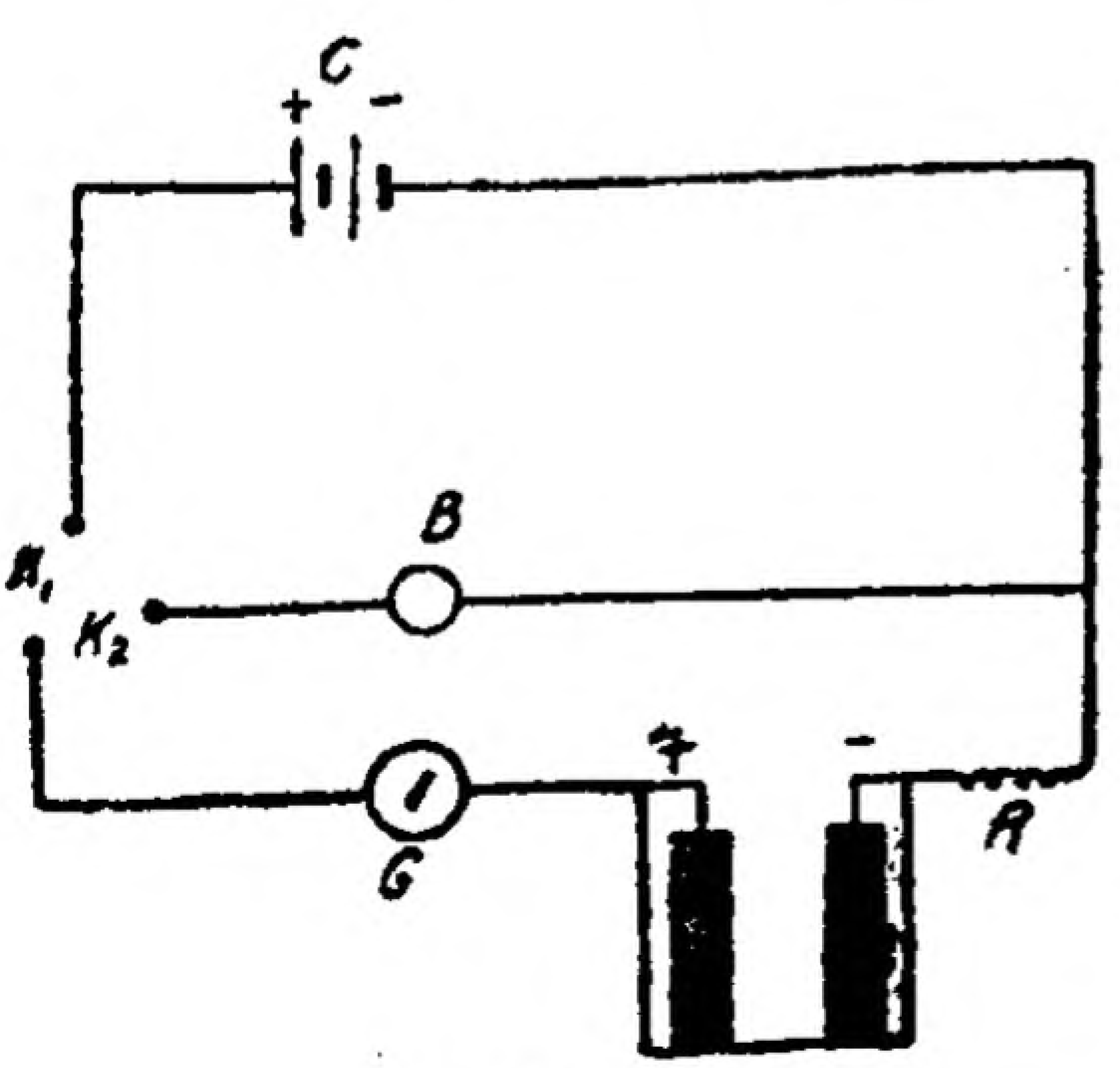


Fig. 169

If the tangent galvanometer has been used, adjust the galvanometer so that the coil lies in the magnetic meridian and the pointer is at zero.

Insert the plug K_2 in its position and see that K_1 is out. Now the battery C is out of circiut, the bell does not ring and the galvanometer shows no deflection, which means that there is no current in the circuit B, K_2, G and R. Now remove K_2 and insert the plug K_1 and allow the current to pass from the battery C for 5 to 10 minutes. If the galvanometer shows small deflection, adjust the rheostat and decrease the deflection. As the current flows, hydrogen will be seen to rise from the cathode, while the other plate (anode) will begin to turn dark brown. At the same time the reading of the galvanometer will begin to decrease. The brown coat is of lead dioxide PbO_2 and it has been formed by the oxygen which is given off at the anode.

If the galvanometer reading has decreased a great deal, move the contact of the rheostat to increase it. When the current has been passed for some time, remove the plug from the position K_1 and insert at K_2. Although the battery is now out of circuit, the bell will ring and galvanometer will show a deflection in a direction *opposite* to that of the original current. The current will decrease rapidly as the energy stored in the lead plates is expended in ringing the bell.

The above experiment shows the principle of a storage cell. Really there has been no storage of electricity, but only a storage of chemical energy.

If, however, we want to demonstrate the principle of an accumulator by charging from the city mains we make connection as given in Fig. 173.

Question:—While passing current from the battery, why did the galvanometer reading fall ?

[When PbO_2 is formed on the anode, a back E.M.F. is set up which pushes back against the E. M. F. of the charging battery.]

Question :—Can a single accumulator or a single Bunsen cell be used in the above experiment in place of the charging battery ?

Storage battery ;—The commercial storage cells consist of + and — lead plates, the positive lead plates are covered with lead dioxide (PbO_2) and have brown colour. The negatives are coated with porous spongy lead and have grey appearance. The coating material is pressed into the interstices in the plates. The plates are sandwitched together with one more negative than the positive. All the positive plates are connected to the positive terminal marked + or red and all the negative plates to the negative terminal marked — or black. The plates are placed very close together with insulating separators usually of wood in between. The acid of density 1·215 is used for filling the battery. As the plates are large and their distance from each other is very small, and internal resistance of the battery is very small, and so it can give a current of high amperage. These cells have an efficiency of about 75 p. c., *i. e.*, they give back about three-fourth of the electrical energy used in charging them. The E. M. F. of each cell is 2·1 volts.

Experiment 106.—**To chage a storage battery with current from the city supply mains** (*D. C. supply*).

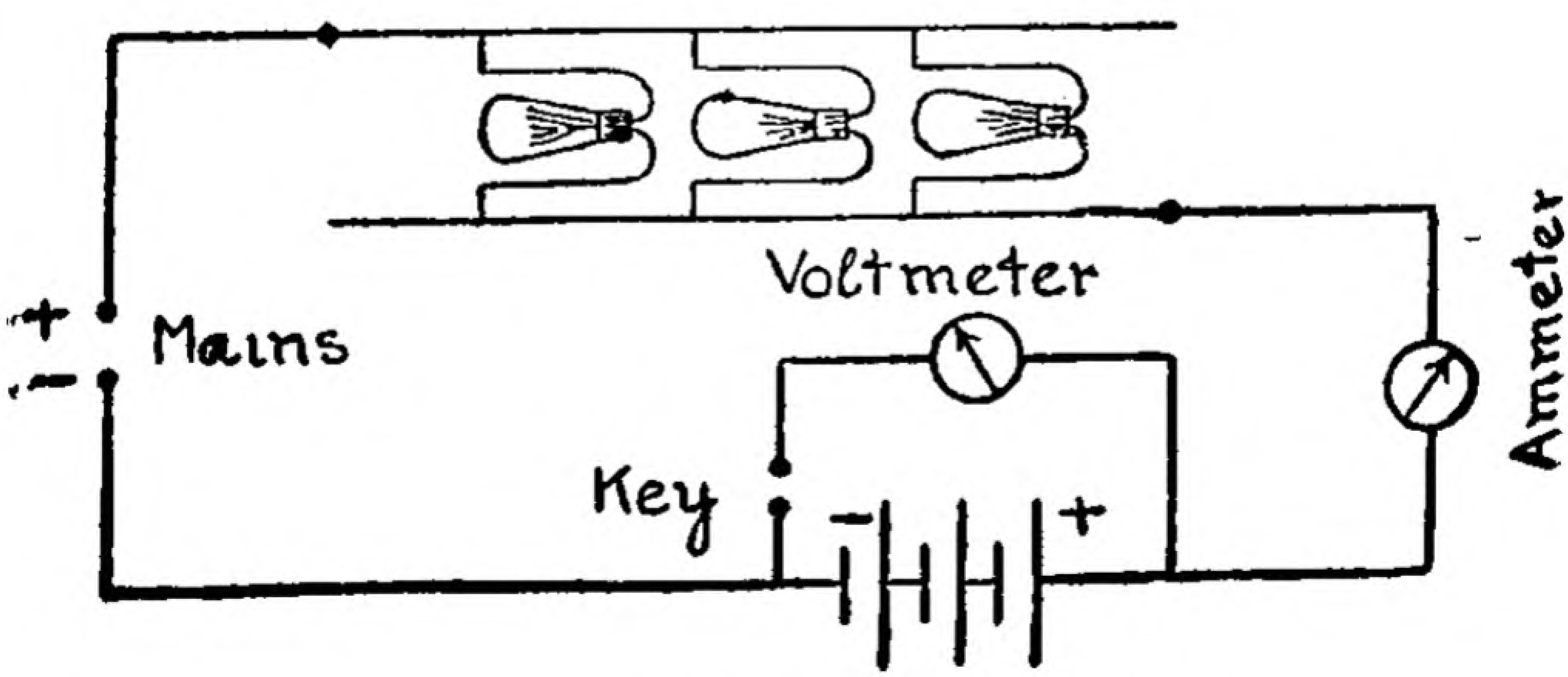


Fig. 170.

Apparatus.—A wooden board with plug having a number of **incandescent lamps joined in parallel on it to serve as vari-**

able resistance or a rheostat, an ammeter, a voltmeter, D.C. supply mains, storage battery, sulphuric acid, distilled water and hydrometer.

Method. Prepare dilute sulphuric acid by adding acid slowly to distilled water, stir continuously and test its density. When the solution is quite cool, the density should be 1·215. Put the acid in the accumulator upto the acid level line. Connect the apparatus as shown in the figure according as you are using a rheostat or a lamp resistance board. With a voltmeter test which terminal from the mains is positive. The positive main is to be connected as shown with the positive terminal of the accumulator marked red.

Next insert lamps of suitable power and adjust their number so that the ammeter reads the current at which

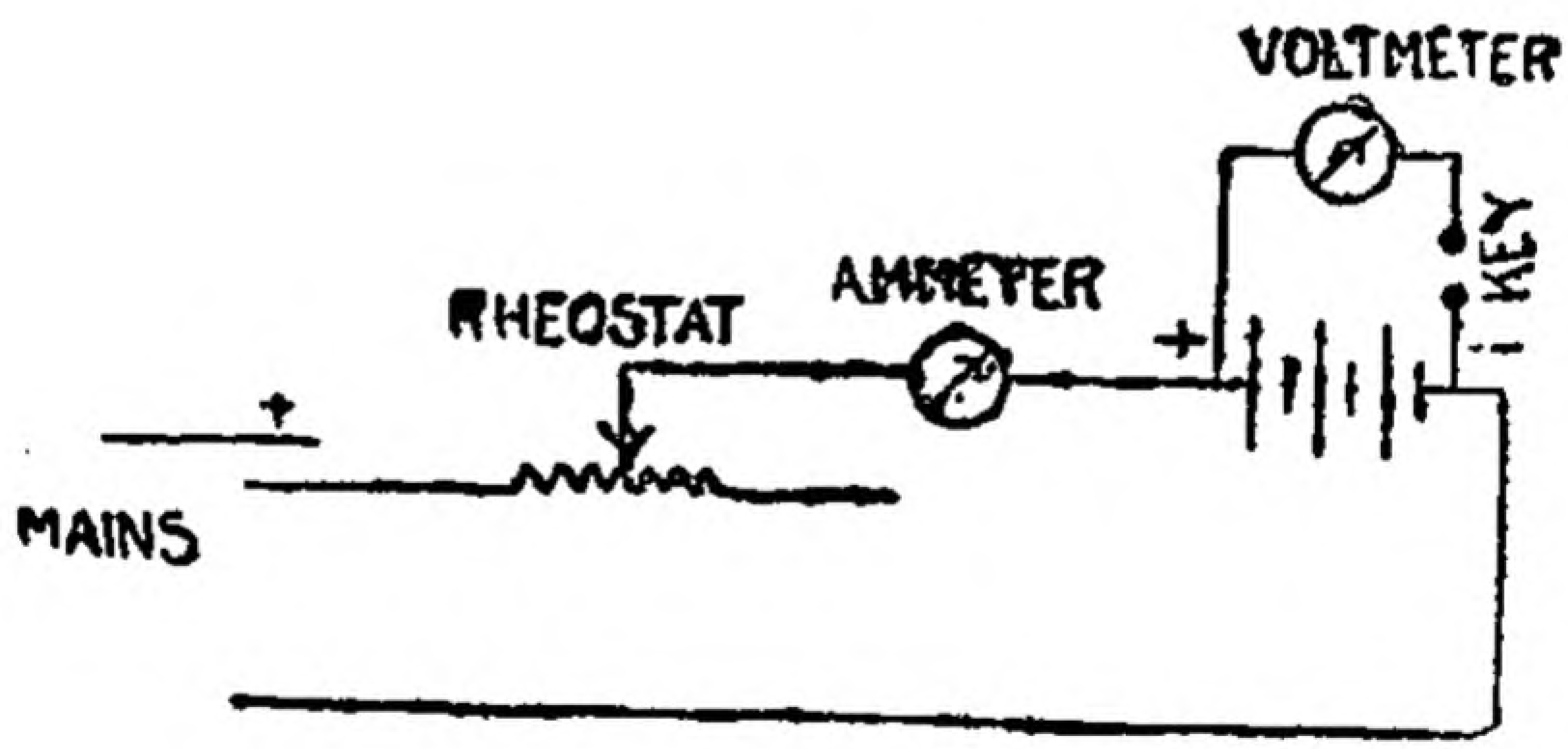


Fig. 171.

makers of accumulator have specified it to be charged. If you are using a rheostat, adjust it so that the ammeter shows the proper current. A voltmeter may be connected across the terminals of the accumulator to ascertain the voltage occasionally, but it is not absolutely necessary to connect it.

On passing the current for some time, bubbling will take

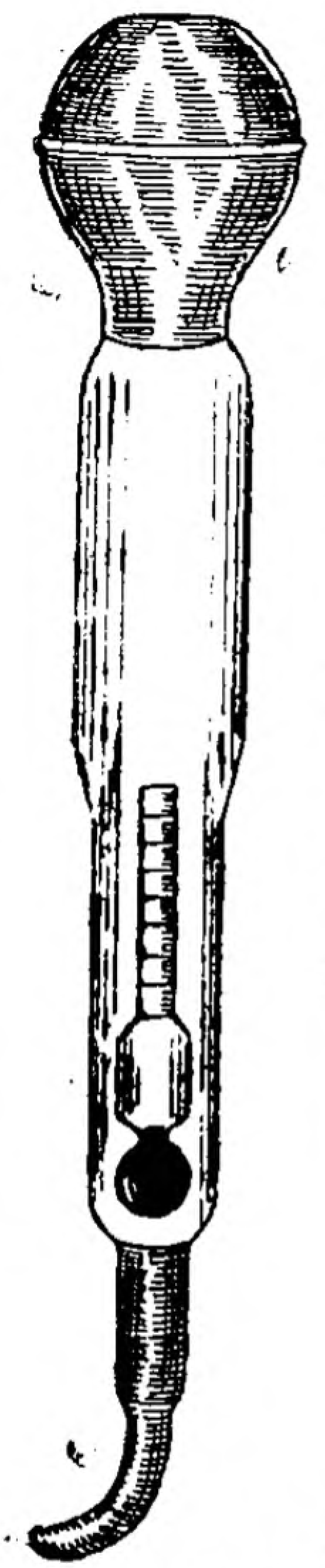


Fig. 172.

place freely at the plates. Continue to charge for about 36 hours, till the voltage of each cell becomes and remains 2·1. Occasionally test the density of the electrolyte by means of a hydrometer which in a fully charged accumulator should be 1·290.

In the case of small accumulators, if need be wire resistance or a rheostat may also be inserted in addition to the incandescent lamps.

Fig. 172 represents the hydrometer usually used for testing the battery acid.

When a cell has been once charged and after that discharged, the chemical action which takes place during second and subsequent rechargings is represented by the following equations.

At the anode

$$PbSO_4 + O + H_2O = PbO_2 + H_2SO_4$$

At the cathode

$$PbSO_4 + H_2 = Pb + H_2SO_4$$

Sulphuric acid is liberated during charging and therefore the density of the electrolyte increases.

Note.—An accumulator should be discharged slowly, both the plates which during charging have been changed to Pb and PbO_2 are reduced to **$PbSO_4$** during discharge.

$$Pb + H_2SO_4 + O = PbSO_4 + H_2O$$

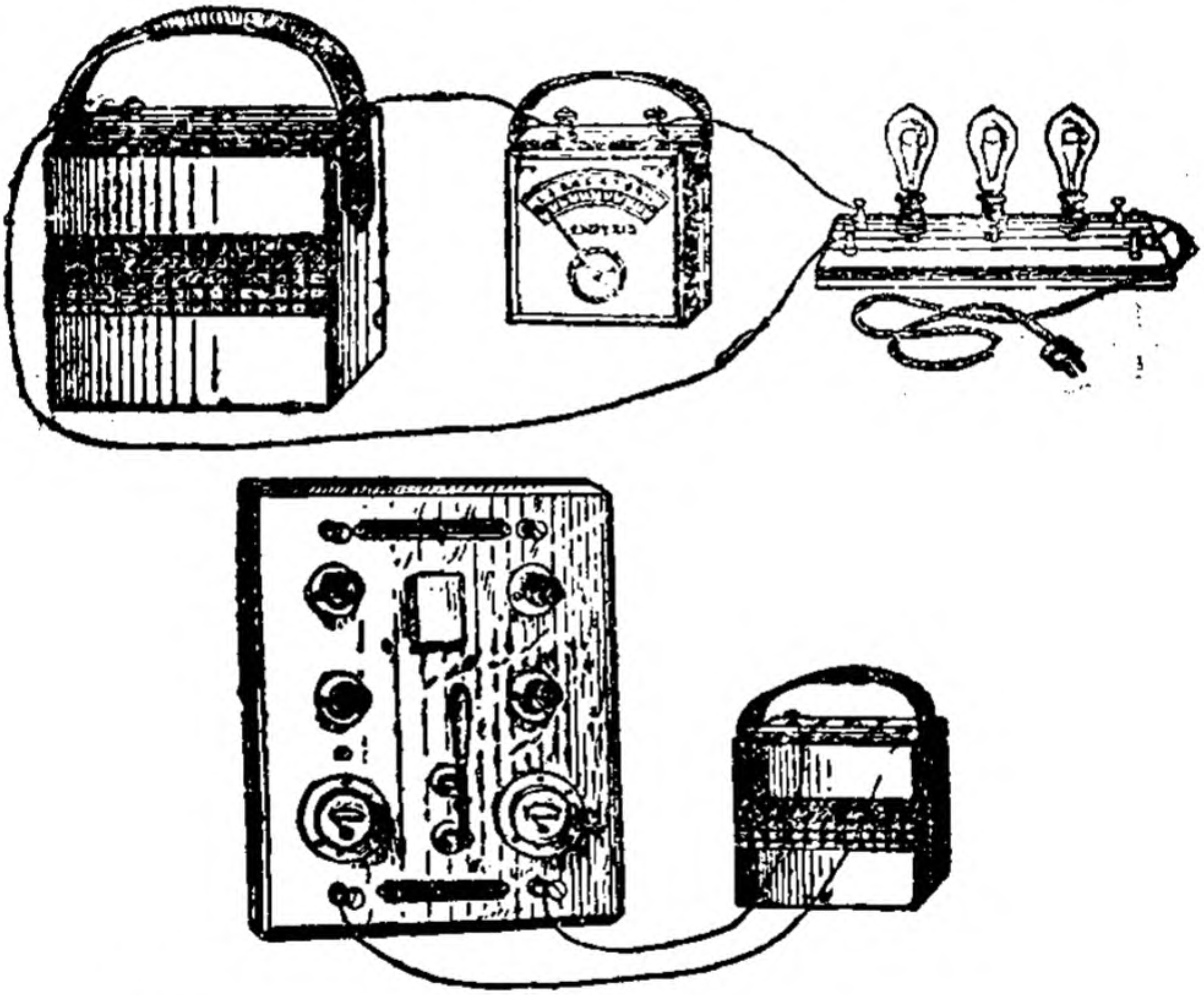
$$PbO_2 + H_2SO_4 + H_2 = PbSO_4 + 2H_2O.$$

Water is liberated during discharging and therefore the density of the electrolyte falls.

Sometimes cities are supplied with alternating current at 110 or 220 volts. Generally the frequency of the alternating current is 40 to 60 cycles per second but it may be 25 as at Srinagar (Kashmir). (The lower frequency, especially if it is not maintained at its proper value, produces ... action on the eye.)

For operating motion pictures and magnetic arc lamps, for charging storage batteries and for various electrochemical industries, direct current is required. We should, therefore, have simple and easy appliances by which it may be possible to convert alternating current into direct supply.

When large quantities of A. C. power are to be changed to D. C. however rotary convertor is used, which is nothing but an A. C. motor coupled to a D. C. generator. While getting such a convertor, voltage and frequency must be specified.



Shows a very convenient charging equipment.

Fig. 173.

For converting small amounts of power, various devices are used, which ars called *rectifiers*. Some of the best known of these are electrolytic rectifiers, (Nodan valves) mercury vapour rectifiers, Vacuum tube (Tunger) rectifiers, and vibrating rectifiers. Of these vacuum tube (Tunger) and vibrating rectifiers are widely used, in these one-half of the cycle is quenched. Theory of these rectifiers is beyond the scope of this book. At one end the alternating current is fed into them and at the other end direct current

at the required voltage is obtained. "Valley charger" made by the General Electric Co. is an example of vibrating rectifier, it can be used for 25 to 60 cycles and is provided with terminals for charging accumulators at 2, 6, 12, 24, 36, 48, 72 and 96 volts. It has got an ammeter also built in it.

Experiment 107. **To charge an accumulator (6 volts) from A. C. main.**

Apparatus.—Rectifier (Tunger) or some other, 6 volts accumulator, ammeter, A. C. supply and connecting wires.

Method.—Connect the A. C. supply to the terminals on the rectifiers for the mains (Fig. 174). Join + (red) terminal of the accumulator to the + of the rectifier and arrange an ammeter and a rheostat (not shown) in series with the accumulator. Adjust the rheostat to get the required amperage and charge as described in the last experiment.

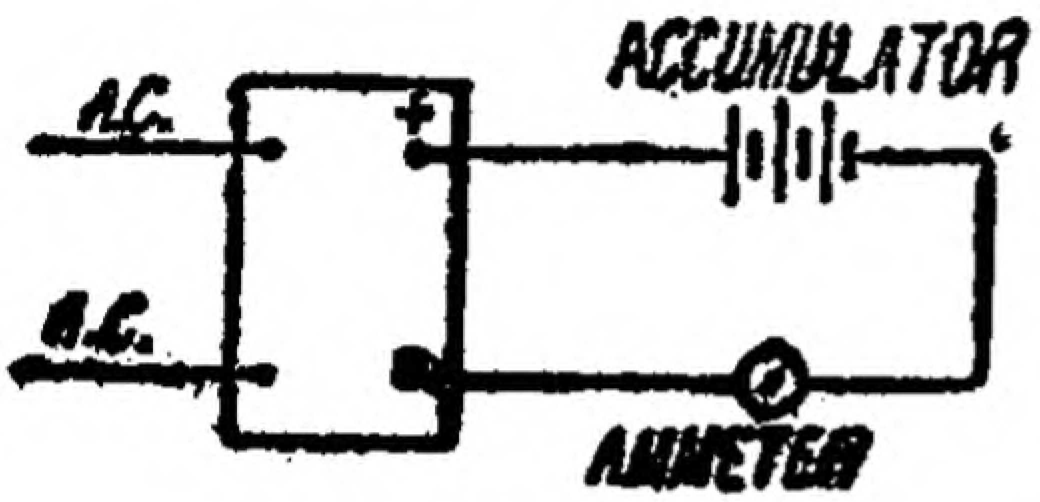


Fig. 174.

CHAPTER XXXIII

ELECTROPLATING

Many household utensils which are made of white metal, brass, iron, steel or copper are plated with silver and nickel. Similarly many articles of jewellery are made of copper or brass and then plated with gold.

When an electric current is passed through the solution of a salt, the salt is decomposed and the metal part of it moves in the direction of the current and is deposited at the cathode.

Preparation of the object for plating. Before an object can be electroplated, it has to be prepared for plating. Greatest care has to be taken that it should be absolutely clean, for the presence of grease, or dirt will spoil the resulting 'plate'.

First the object is secured and polished till it looks perfectly clean, then to remove grease it is attached to a wire and dipped in a hot solution of caustic potash. It is afterwards washed with water, next dipped in dilute acid, then washed thoroughly in water. Care should be taken that after the object has been dipped in caustic potash, it should not be touched with fingers, otherwise the grease of the fingers will spoil its surface and the deposit will not 'take.' For good deposit this preliminary preparation is absolutely necessary.

Electroplating should be done in either stoneware or glass tanks. For work in laboratory, the size 30 cm. $\times 23 \times$ 23 cm. is quite convenient. Bunsen cells can be used as source of current ; a rheostat should be introduced in the circuit to regulate the strength of the current. Deposit adheres better if a relatively small current is used. For getting a good deposit adjust the current so that ***for every 100 square centimetre of area there is a current of $\frac{1}{2}$ to $\frac{2}{3}$ amperes.***

If the deposit is to take place on one side only then the area of one side is to be considered.

If the deposit is to take place on two sides then consider the area of two sides. When amperage is high, plating will be crystalline and will scale off. To hasten the process of plating, more amperes may be used provided the electrolyte is continuously stirred.

The article to be plated is suspended from a brass or copper rod and is made a cathode and on either side of it are suspended two anodes made of the same metal which is to be deposited from the solution.

The solution used for copper plating is copper sulphate which has been rendered slightly acidic by the addition of sulphuric acid. Nickel is deposited from a solution of nickel sulphate and ammonium sulphate. Silver from double cyanide of silver and potassium and gold from double cyanide of gold and potassium. It should, however, be borne in mind that for copper plating on brass articles, acid electrolyte as stated above is suitable, but in the case of iron and steel articles, acid electrolyte produces corrosive action, therefore, we should use alkaline bath, *i.e.*, the electrolyte should be of some copper salt to which potassium cyanide and ammonium had been added. In gold plating reddish tinge can by imparted to the gold deposit by adding a small quantity of copper cyanide to the electrolyte.

If any portion is not desired to be plated that should be covered with a coating of wax.

Experiment 108. **To electroplate a spoon with nickel.**

Apparatus.—Electroplating tank, spoon, a battery of two Bunsen cells, an ammeter a rheostat, nickel ammonium sulphate and ammonium sulphate, two rods of pure nickle, emery paper, plug key.

Method.—Clean the spoon thoroughly by rubbing it with sand brush or saw dust, wash it in clean water and remove the grease as already described by dipping it in hot solution of caustic potash etc. Prepare the solution of nickel ammonium sulphate and ammonium sulphate and put them in the tank. Suspend the spoon from the cathode,

on either side of which we have two anodes of pure nickel as shown in the figure.

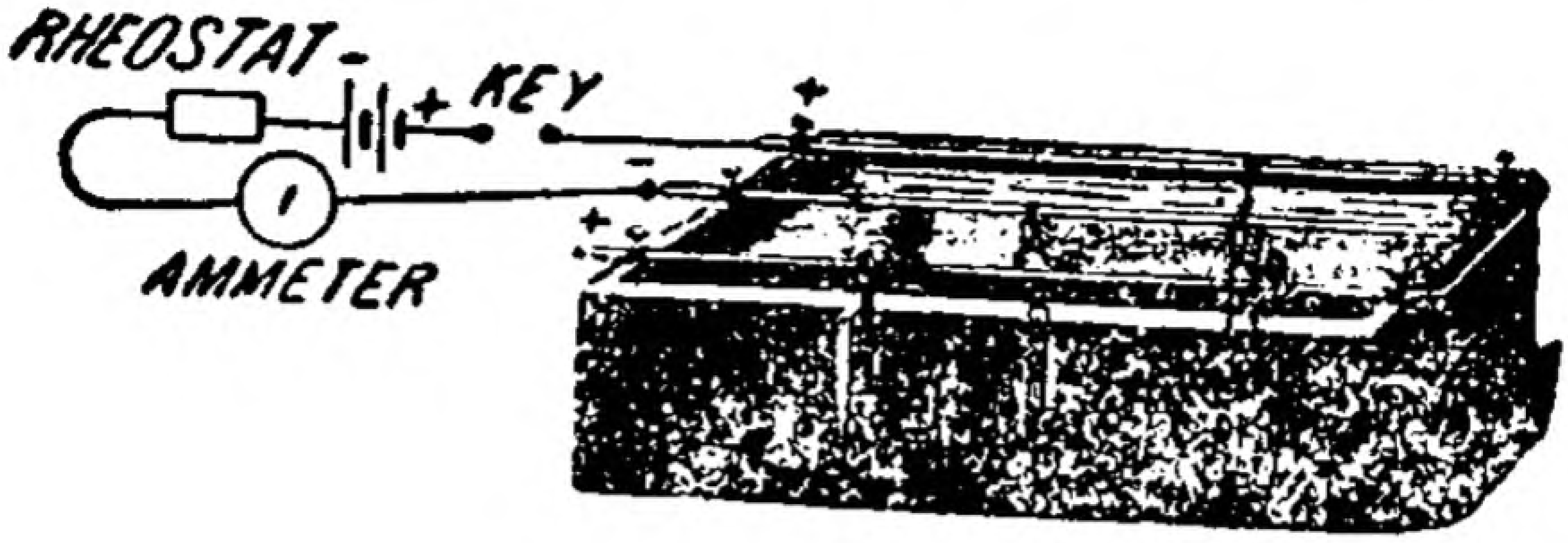


Fig. 175.

Include a rheostat and an ammeter in the circuit, use the rheostat so that a current of about ·15 amperes or even less flows. If the amperage will be small, plating will be fine. Pass the current for about half an hour or so, remove the spoon, wash it with clean water and polish to give it a bright surface.

Exercise.—Electroplate a fork with copper.

[Use a simple Bunsen cell or an accumulator as source of current. Electrolyte is copper sulphate to which a little of sulphuric acid has been added. Find out approximately the area of the fork, adjust the rheostat so that for every 100 sq. cms., of the area there is a current of $\frac{1}{2}$ to $\frac{2}{3}$ amperes.

A very simple arrangement is shown in (Fig. 176). The object to be electroplated is connected with the negative of the cell, but for better results the cathode should have an anode on its either side.]

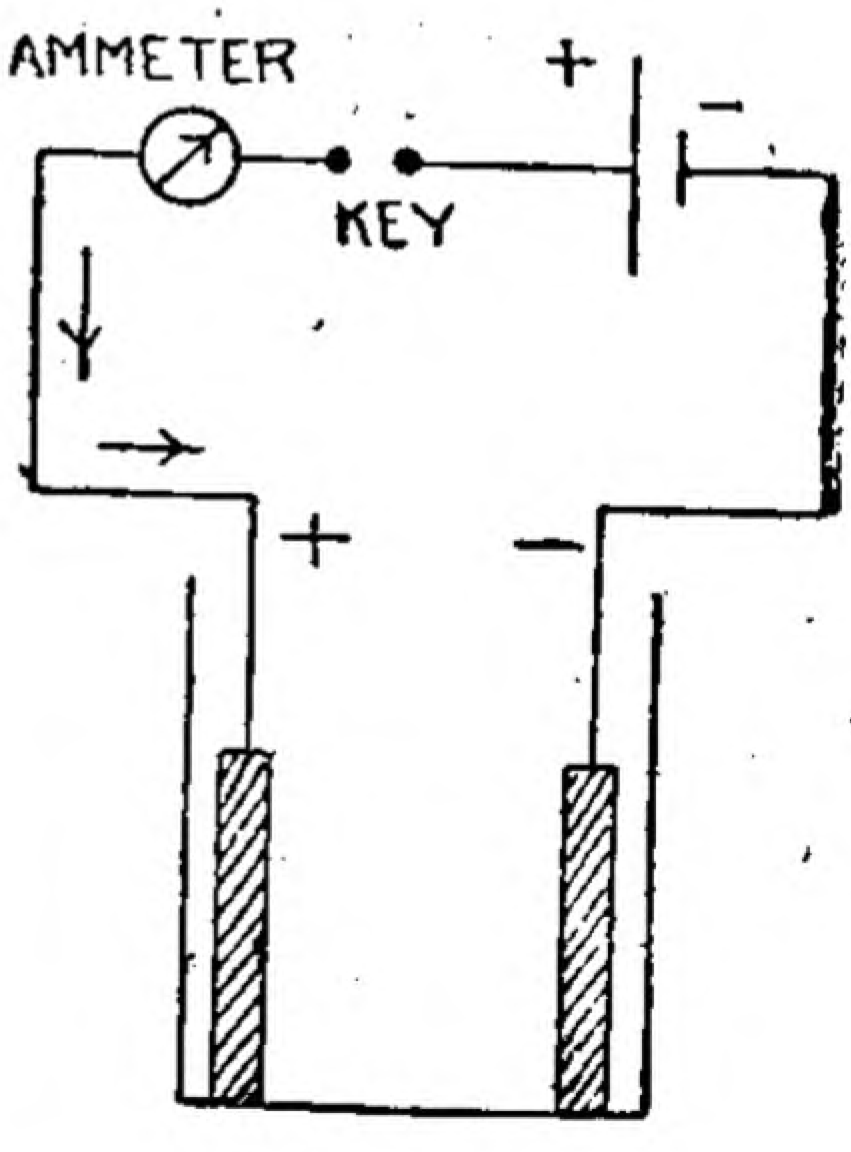


Fig. 176.

Experiment 109. **To determine the electrochemical equivalent of copper.**

Apparatus.—Copper voltameter, battery, key, resistance box or rheostat, ammeter or milliammeter, stop-watch, a weight box.

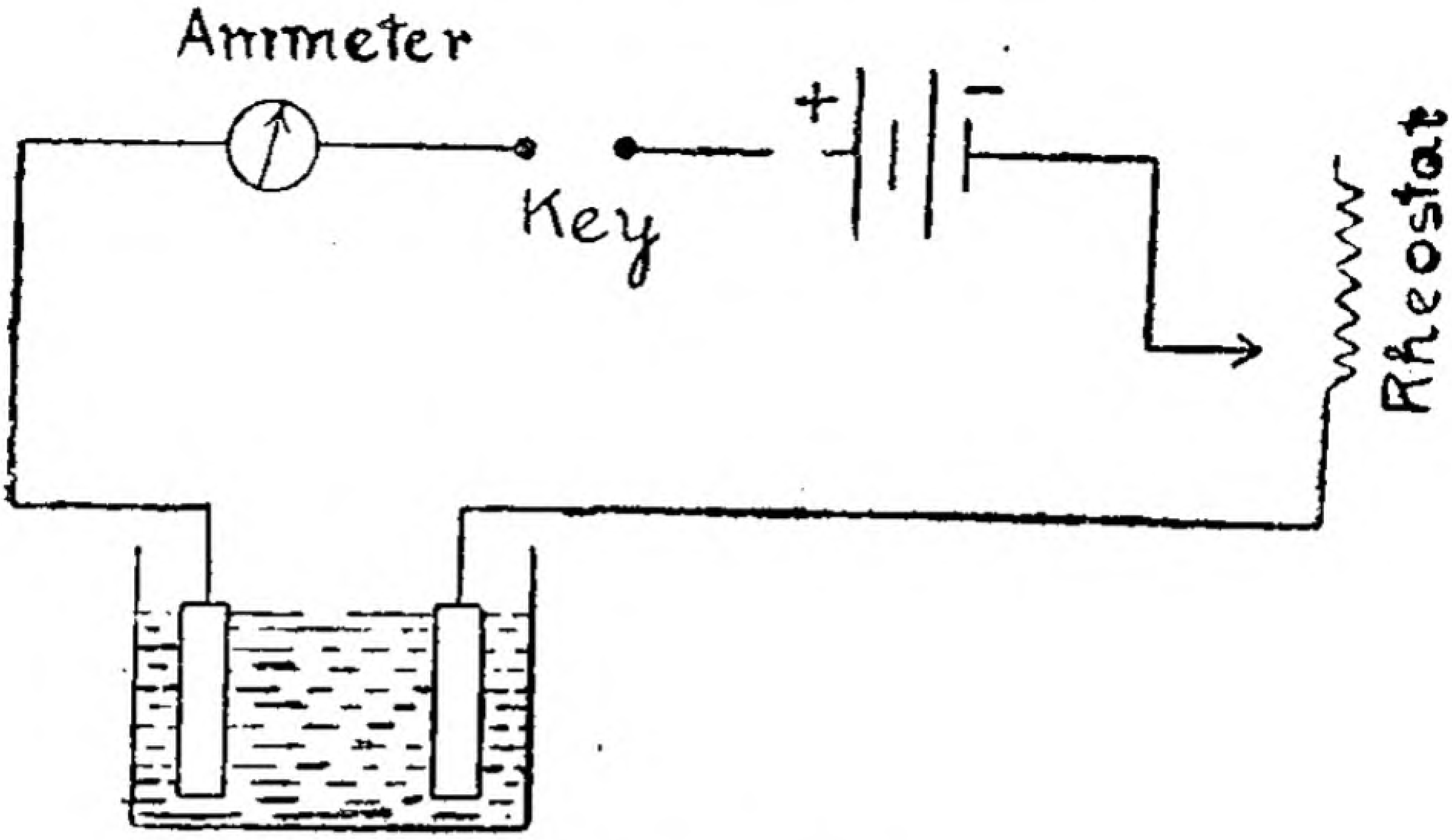


Fig. 177.

Method—In this experiment, a copper voltameter is to be used. It consists of a glass vessel containing solution of copper sulphate with copper electrodes immersed in it.

The plate which is to be made the cathode is thoroughly cleaned. No grease or oxide is allowed to remain on its surface. The plate is, at first, rubbed with sand paper and then washed with caustic potash solution. It is washed with water and dried. After the cathode has been thoroughly cleaned, weigh it accurately, and then immerse it in the copper sulphate solution. Make the connections as shown in figure (177). The cathode is connected through a rheostat or a resistance box to the negative pole of the battery. The anode is connected through an ammeter to the positive pole of the battery.

Use a key in the circuit as shown in Fig. 177. In case the electrodes of the copper voltameter are quite close to one another, place a glass plate between them so as to keep them separate. Close the circuit and adjust the rheostat till a current of one ampere begins to flow for every sixty square centimetres of the surface to be plated. Start the stop-watch the moment the circuit is completed, and allow the current to flow for at least $\frac{1}{2}$ hour (1800 seconds). Record the strength of the current after every minute. After breaking the circuit, remove the cathode and wash it with water so as to remove copper sulphate solution from its surface.

Make the plate dry either with the help of hot air or by pouring a little quantity of spirit over its surface and allowing it to evaporate. Then weigh the dried plate and find the amount of copper deposited.

If M be the mass of copper deposited, Z the electrochemical equivalent of copper, C the current in amperes and t the time in seconds, then

$$M = ZCt.$$

$$\text{Therefore } Z = \frac{M}{C \times t}$$

Record your observations as given below :

Initial weight of copper plate =

Final weight of copper plate =

$\therefore$ amount of copper deposited =

Time = ...seconds

Strength of current = (1) (2) (3) (4) (5) (6)

Mean = ... amperes.

$$Z = \frac{M}{C \times t.} = \text{ grams per coulomb.}$$

Precautions : 1. The plate should be thoroughly cleaned so that there is no grease or oxide sticking to its surface otherwise the deposit would not be uniform and well adherent.

2. The plate should be weighed accurately by the method of oscillations, if possible.

3. The strength of current must be properly adjusted so that the deposit may not be brittle.

CHAPTER XXXIV

RESISTANCE BOXES, RHEOSTATS AND GALVANOMETERS

Resistance boxes.—For comparison and measurement of resistances, it is necessary that we should have a unit of resistant (Ohm). For our purpose, it will be quite sufficient if we were to have pieces of wires having a resistance of 1 Ohm, 2 Ohms, 3 Ohms, or any number of Ohms. Generally such wires are arranged in resistance boxes, which consists of a series of silk covered coils would on a bobbin and they can be used in any combination. The wires used are made of certain alloys such as German silver, platinoid, managanin etc., these are selected both on account of their high specific resistance and small variation in resistance due to any change in temperature. In all cases, in order to remove self-induction the wire is doubled on itself at its middle and is then wound, these are also soaked in paraffin wax to protect them from damp. The coils are enclosed in a box which is fitted with an ebonite top. The ends of the coil are brought through the ebonite and connected to thick brass blocks placed on the top of the ebonite. Plugs made of

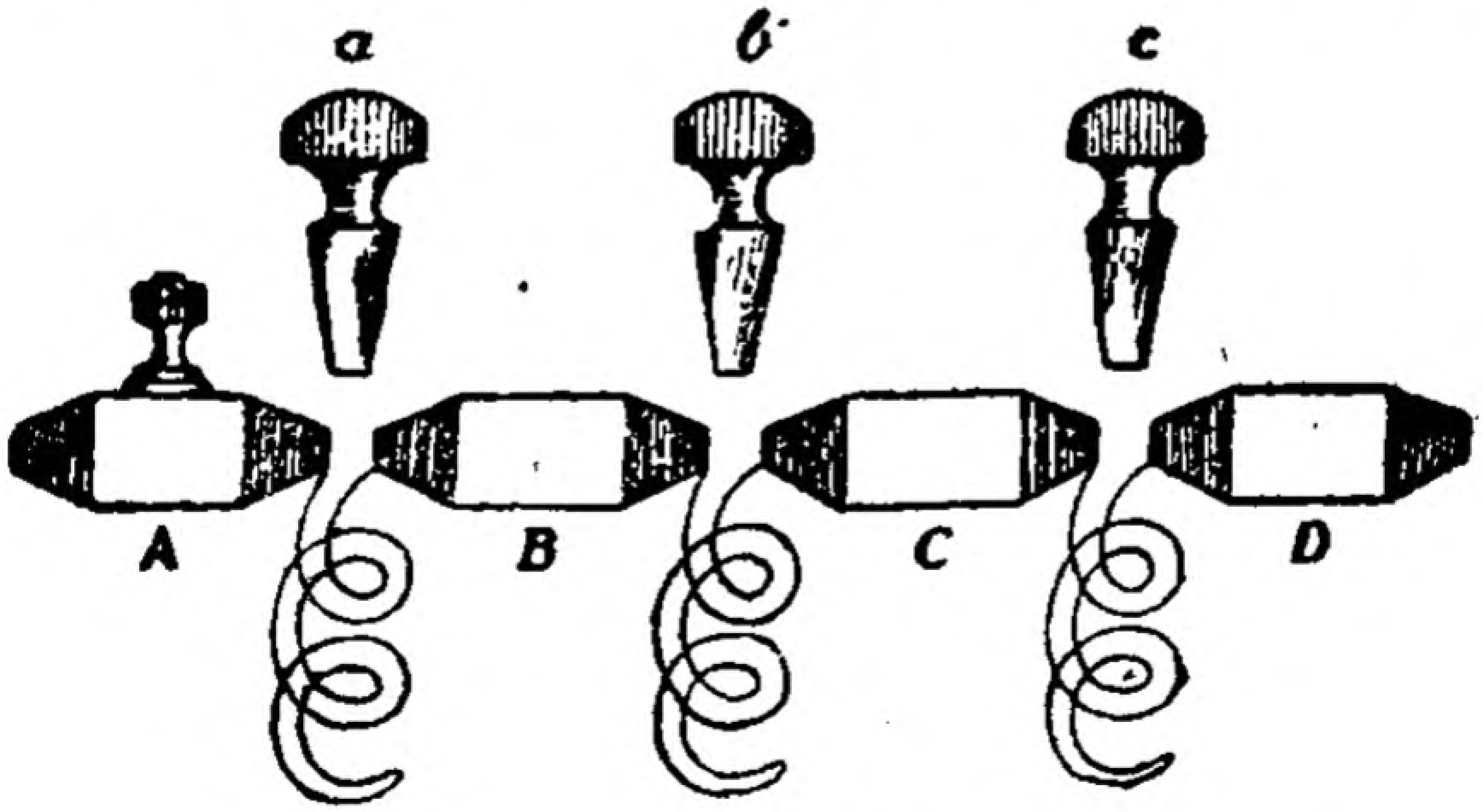


Fig. 178.

stout brass and having ebonite tops are fitted in the brass blocks as shown in Fig. 178. If the plugs are in, the current is led to A, it flows straight through ABCD because this path

offers very little resistance but if the plugs are out, the current has necessarily to pass through the coil. it will thus meet with the resistance offered by the coils.

In using a resistance box, the following precautions should always be taken.

(*a*) Insert and remove the plug with screwing motion in addition to the push or pull required for the purpose.

(*b*) When the plug has been removed, tighten the plugs on either side of it, for the brass blocks on account of the pressure having been removed will have sprung slightly towards the vacant hole. Failure to do this leads to failure in many experiments.

(*c*) Do not pass heavy current through a resistance box, otherwise the coils will be heated and might get burnt. Take special care when you are using accumulators as source of current.

(*d*) Keep the ebonite surface always clean.

(*e*) The brass portion of the plugs should always be bright, but never rub them with emery paper. If these have to be cleaned clean them with brasso.

(*f*) See that there are no dust particles in the gaps between the blocks of brass.

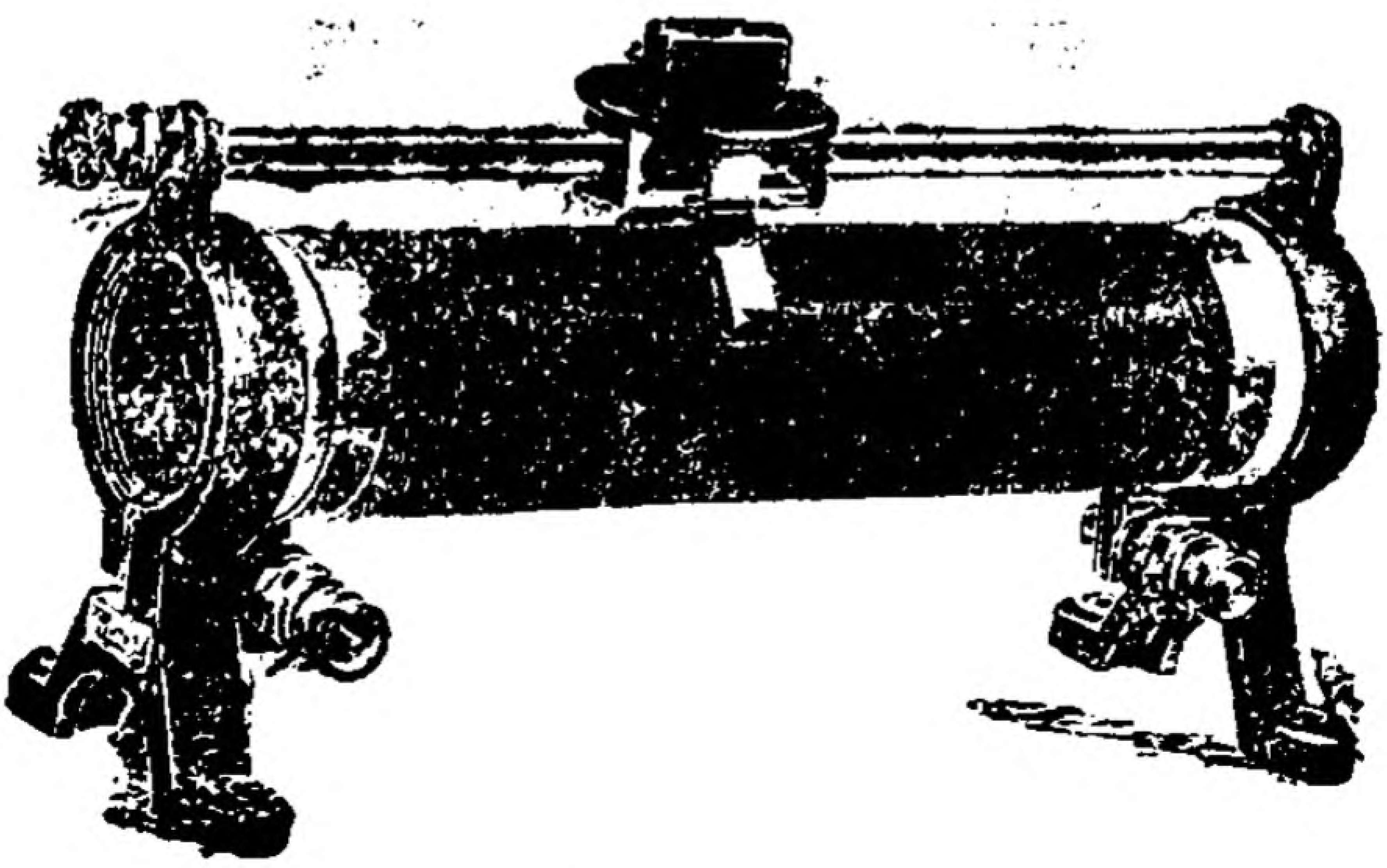


Fig. 179.

Sliding ~~rheostat~~. It is an adjustable unknown resistance. Fig. 179 represents a convenient form. The resistance wire is wound round an insulating cylinder. The sliding contact can be moved parallel to the length of the cylinder and makes contact with the resistance. It carries a terminal which takes away the current.

Galvanometers. The magnetic effect of a current can be used for detecting its presence and measuring its strength. *The term galvanometer is applied to the instruments which measure the strength of currents.* There are various types of instrument in use but we shall consider here only two.

(*a*) *Tangent galvanometer* and (*b*) *Suspended coil pointer type galvanometer.*

Tangent galvanometer. Fig. 180 represents a tangent galvanometer. It generally consists of three separate coils of 2, 50 and 500 turns of wire wound on the same wooden ring and placed in the same groove, they have got slightly different radii. These wires are joined to 4 terminals, so that they can be used separately or together. At the centre of the coils is placed a short magnet which carries a

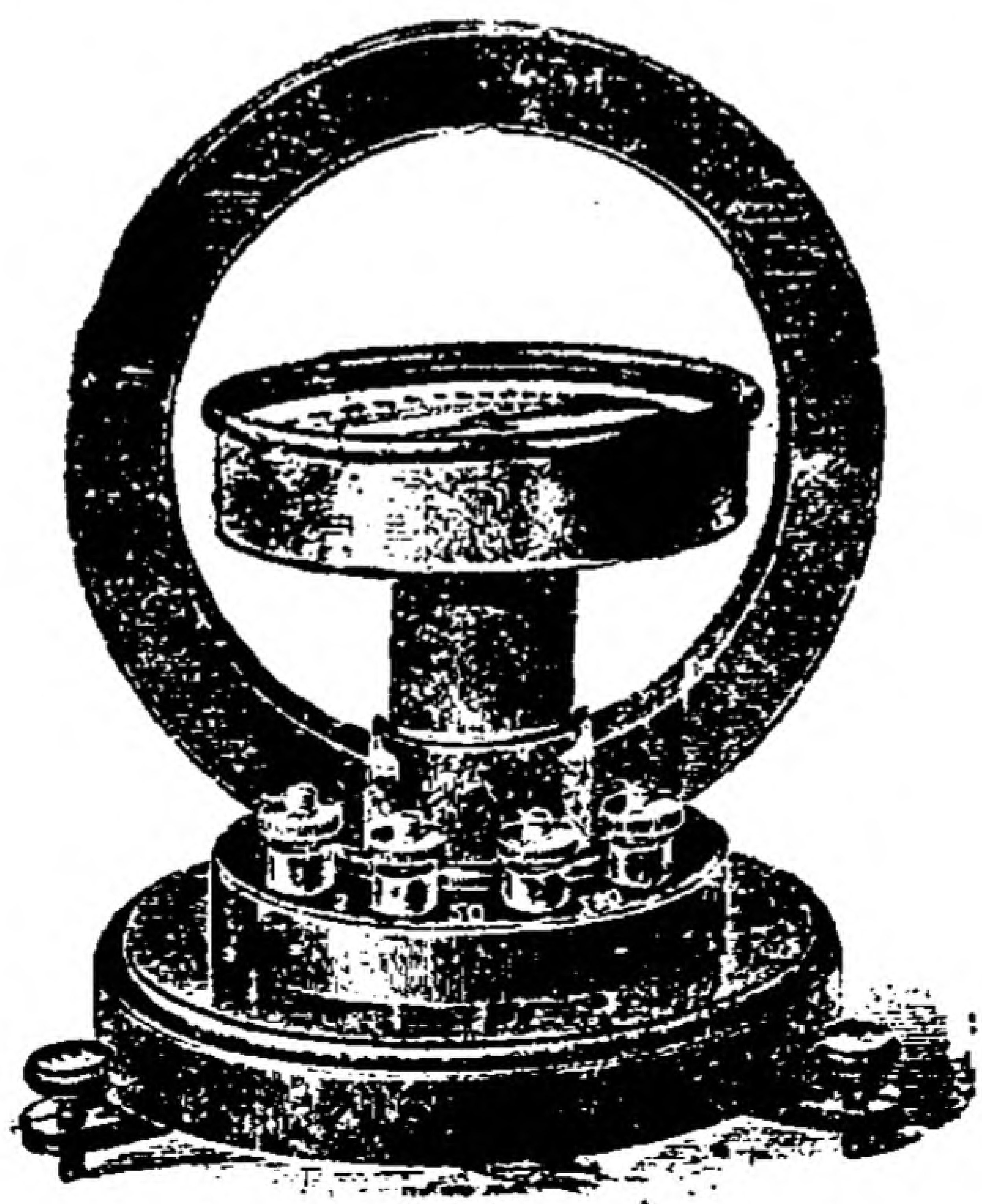


Fig. 180

long but light aluminium pointer, the ends of this move over a circle graduated in degrees. There is also placed a mirror underneath the scale to avoid error of parallax. The wooden ring containing the coils is capable of rotation about a fixed axis.

We know that if a wire l cms. long be bent in the form of a circle of radius r and a current C be passed in it, the magnetic field at the centre is given by $F=\frac{lC}{r^2}$. If this wire has been bent so as to have n turns then $l=2\pi rn$.

$$\therefore F=\frac{2\pi rnc}{r^2}=\frac{2\pi nC}{r}.$$

When going to use the tangent galvanometer, its coil has to be turned till it is in the magnetic meridian. In this position when the current is passed through the coil, the magnetic force due to it is at right angles to the meridian. The magnetic needle is thus acted on by the force F and by the horizontal component H of the earth's field. As these forces are acting perpendicularly to each other, the needle will be deflected from the direction of the earth's field through an angle θ. In this position $F=H\tan\theta$.

$$\text{But } F=\frac{2\pi nC}{r}$$

$$\therefore \quad \frac{2\pi nC}{r}=H\tan\theta,$$

$$\text{or} \qquad C=\frac{rH}{2\pi n}\tan\theta,$$

where C is in absolute units.

Since 10 amperes are equal to one absolute unit of current, the above equation may be written

$$C=\frac{10rH}{2\pi n}\tan\theta,$$

C being in amperes.

As the factor $\frac{10r}{2n\pi}$ is constant for a particular galvanometer at a particular place, it is generally denoted by $\frac{1}{G}$ and

$\frac{H}{G}$ is put $=K$, which is called the *reduction factor.* Current is in terms of tangent of angle of deflection—hence the name tangent galvanometer.

Adjustments.—When using a tangent galvanometer the following adjustments have to be made.

(*a*) Level the instrument so that the coil is vertical and see that the needle swings freely and that it and the pointer are not dipping in any direction. Observe whether the needle always comes to rest at the same place or not. If not and in addition to it, its movements are slow and sluggish, most probably it has lost much of its magnetism, the instrument therefore should be changed.

(*b*) Turn the coil in the magnetic meridian, the small magnet should now be in the plane of the coil and the pointer attached to it should read zero zero. To see whether the coil has been placed in the magnetic meridian or not look down into the instrument and place your eye so that the edge of the coil just covers the image of the edge in the anti-parallax mirror placed below the scale. With the eye in this position, the edge should cut the scale on either side of the zero at the same graduation. If it does not, turn round the *compass box* (not the coil) till the above condition is satisfied. In this position the zero line is perpendicular to the plane of the coil.

(*c*) Next turn the instrument (coil and compass) till at least on one side the pointer reads zero.

(*d*) If the needle is pivoted, tap the instrument gently with your finger or pencil before the position of the pointer is read on the scale.

(*e*) For finding the deflection **do not calculate zero correction**, read both ends of the pointer. In this way error due to eccentricity will be eliminated. Reverse the current and again take readings of both ends of the pointer. Mean of these four readings will give the value of the deflection.

(*f*) The resistance in the circuit should be so arranged that the deflection should lie between 30° and 60°. Within this range the error made in taking observations will have slight effect. This error is minimum when the deflection is 45°.

Moving coil pointer type galvanometers :—A very convenient type is shown in Fig. 181 It does not require levelling or setting in any particular direction as in the case of tangent galvanometers. It has got an arbitrary scale of equal division and is generally used for detecting the presence of currents in null methods. While using such galvanometers, care should be taken not to pass heavy currents otherwise the portion near the joint with the pointer will be fused. In these galvanometers the coil is placed between the poles of a very powerful permanent magnet.

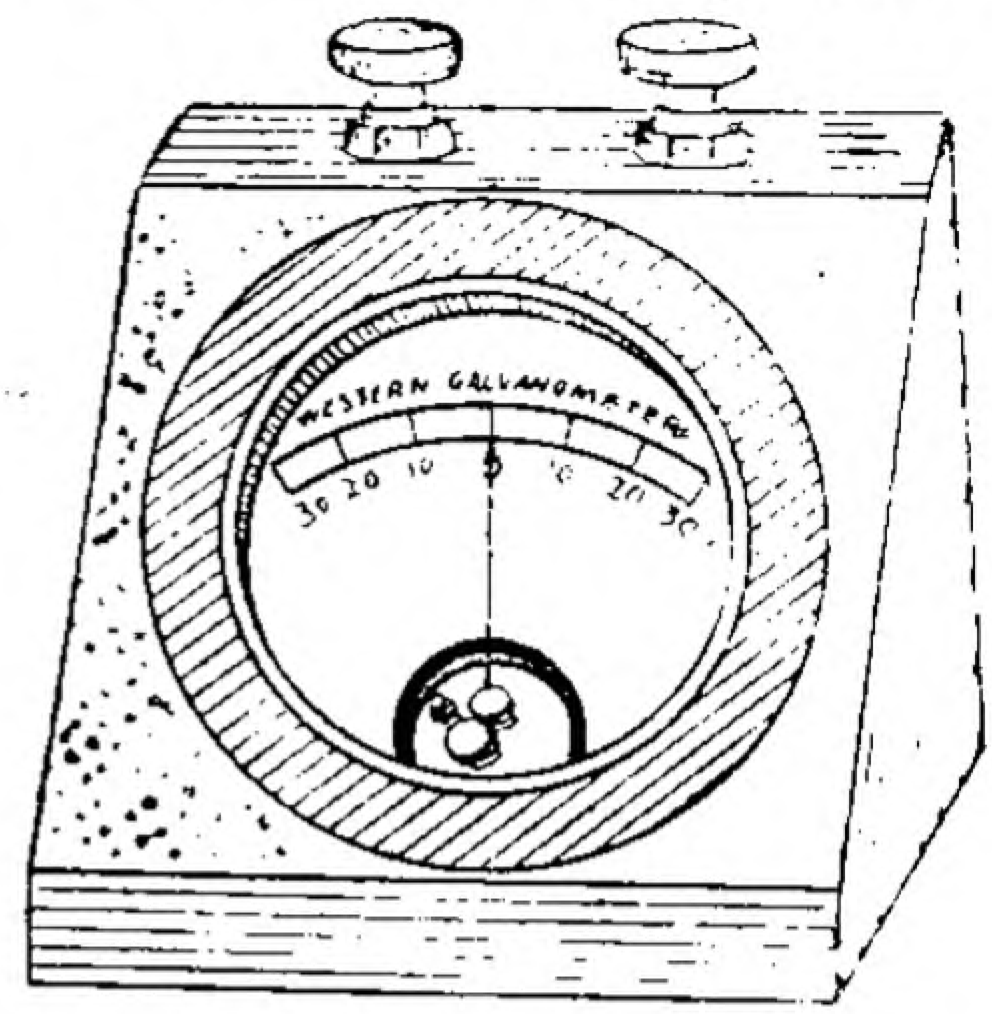


Fig. 181

Ammeters :—These are nothing but galvanometers of low resistance, graduated in such a way as to read the strength of currents directly in amperes or fractions of an ampere (Fig. 182). In the case of moving coil type instruments, the coil is mounted on pivots between the poles of a powerful magnet and its motion is controlled by hair springs. Some instruments are designed to work at different ranges and are provided with suitable shunts. An ammeter must have low resistance so that when it is inserted in the circuit, it does not materially alter the strength of a current. The requisites of a good ammeter are (*a*) accuracy ; (*b*) low resistance.

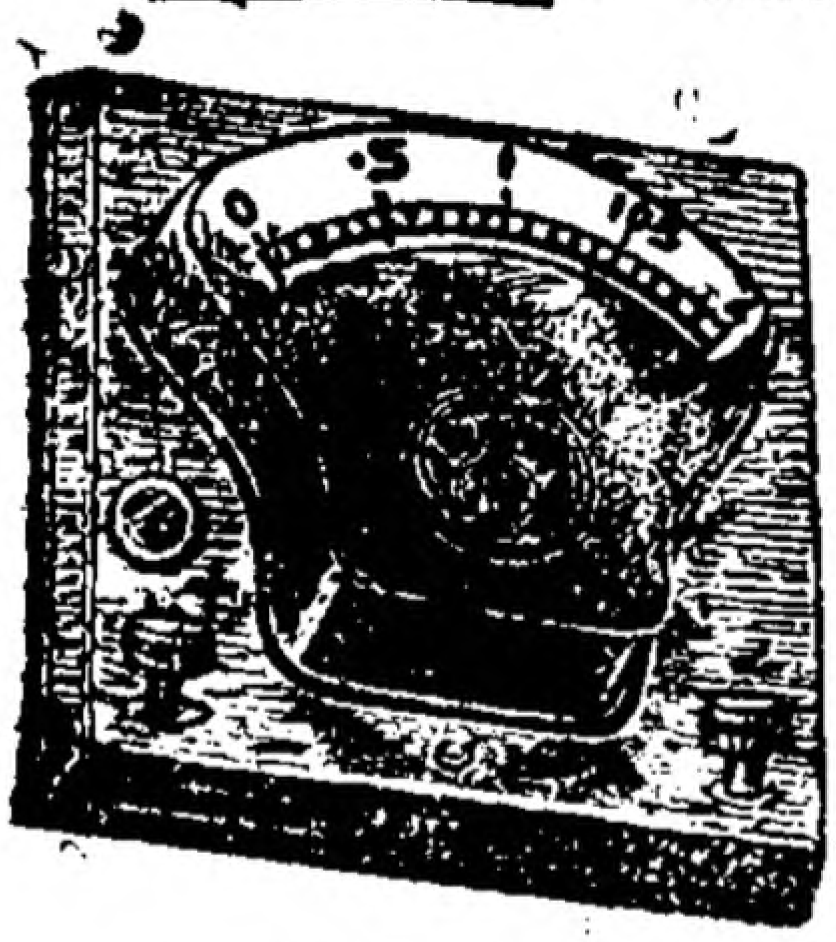


Fig. 182

An ammeter is always connected in series with other parts of the circuit.

Voltmeter.- Voltmeter is a high resistance galvanometer and we always assume that the current flowing in it is negligibly small. The higher the resistance of the instrument, the more accurately will this condition be satisfied. **A voltmeter should always be connected in parallel.**

NOTE. The accuracy in the case of ammeters and voltmeters is limited, they give correct value within

CHAPTER XXXV

MEASUREMENT OF RESISTANCE

When the same electromotive force is applied to two circuits, it is not necessary that the same amount of current should traverse through them. The strength of the current produced not only depends on the E. M. F. applied but also on another factor called the **resistance.**

Dr. G. S. Ohm from his experimental results has deduced and stated a law, which is known after his name.

Ohm's Law. In any simple circuit the ratio of the electromotive force producing a current to the current produced is a constant, which depends only on the material, form and physical conditions of the circuit. This constant is termed the *resistance of the circuit.*

Expressed in symbols, the law states

$$\frac{E}{C} = \text{a constant} = R.$$

Ohm's Law is true not only for the whole of the circuit but also for a part of it. When only a part of the circuit outside a cell or a dynamo is considered the law states :—

$$\frac{\text{Potential difference}}{\text{Current}} \text{ is a constant.}$$

When potential difference is measured in volts, and current in amperes, the resistance is in Ohms.

$$\frac{\text{P. D. in Volts}}{\text{Current in Amperes}} = \text{Resistance in Ohms.}$$

For purposes of practical measurements, the *International Ohm* is defined as the resistance of a column of mercury 130·6 cm. long and 1 sq. mm., in area of cross section at a temperature of 0^0C.

The reciprocal of resistance, *i.e.*, $\frac{1}{R}$ is called *conductance*.

Experiment 110.—**To verify Ohm's law with the help of ammeter and voltmeter.**

Apparatus.—A wire of manganin or of some other alloy about a metre in length stretched on a board, (slide wire bridge will do), a voltmeter and an ammeter both reading to ·05 of a volt and an ampere, rheostat, and an accumulator or a Daniel cell and a plug key.

Method. Arrange the apparatus as shown in the Fig. 183.

A B is the manganin wire. Put the ammeter and the rheostat in series with the wire A B and the voltmeter in parallel with it.

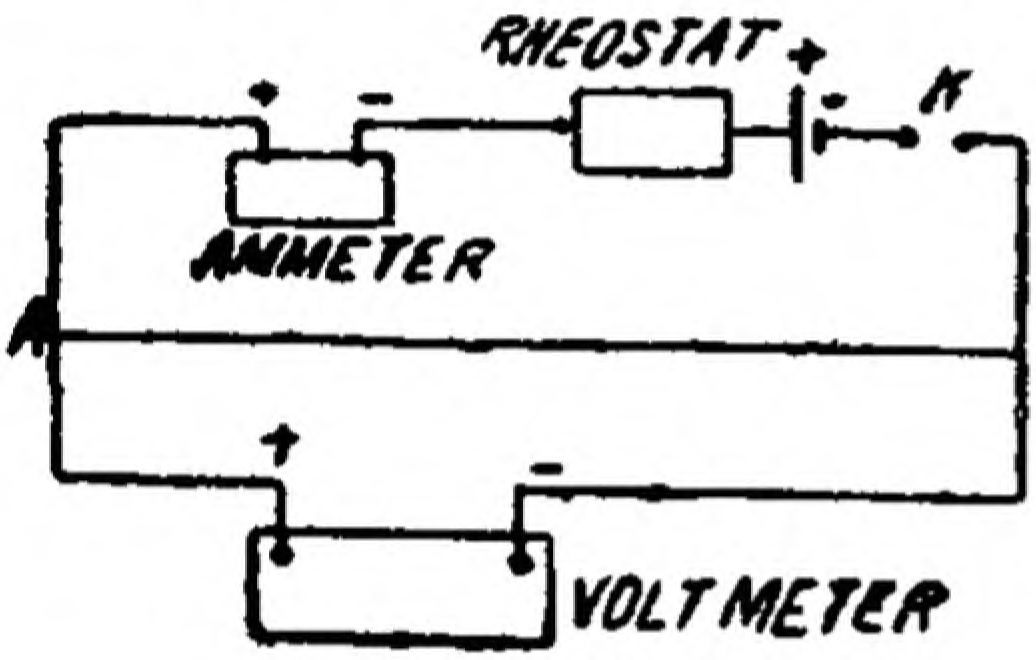


Fig. 183.

Adjust the rheostat so that a small current which can be read accurately traverses the circuit. Note the reading of the ammeter as well as that of voltmeter. Next increase the current by shifting the contact point of the rheostat and read both ammeter and voltmeter. Continue the process and take several readings. Tabulate your results thus :

Reading of voltmeter or Potential difference P. D. (volts)	Reading of ammeter or Current C (amp)	$\frac{\text{P.D.}}{\text{current}}$

Precautions.—1. The terminals marked + on the ammeter and the voltmeter should be connected to the + pole of the battery, similarly — terminals to the negative pole.

2. Key must be inserted in the circuit and the curren should be passed for a short time only *i.e.*, for a time ju sufficient to note the readings.

3. Clean the ends of the wires with sand paper.

4. See that all the connections are tight.

Verification of Ohm's law with tangent galvanometer :-

If ammeter and voltmeter with finely divided scale are n available, the experiment can be performed with tange galvanometers. In this case a commutator should be intro duced in the battery circuit and connections should b made as shown in Fig. 184.

The rheostat if not available can be replaced by resistance box, but with a rheostat the results are better.

Use 50 turns in the case of the galvanometer P an 500 turns in that of Q. Adjust both the galvanometers.

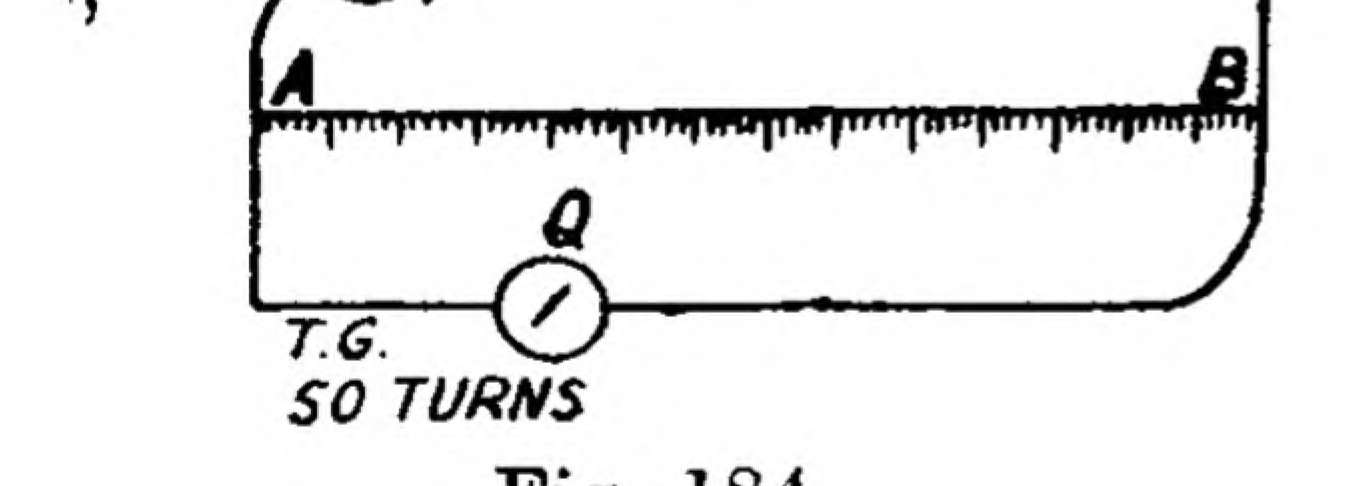


Fig. 184.

Take out a sma resistance, say 1 ohm from the box and not down the deflection of both the ends of the tw galvanometers. The reverse the current an again note the deflec tions. Find out mea deflection for each of th galvanometers P and Q. Next change the resis tance slightly and repeat the observations. Repeat the proces three times. Resistance taken out from the box shoul not be more than 3 or 4 ohms.

Show that $\frac{\tan \theta_2}{\tan \theta_1}$ = a constant.

Tabulate your results thus.

Resistance taken out	Galvanometer P.						Galvanometer Q.						$\frac{\tan\theta_2}{\tan\theta_1}$
	Direct current		Reversed current		Mean θ_1	Tan θ_1	Direct current		Reversed current		Mean θ_2	Tan θ_2	
	E. end.	W. end.	E. end.	W. end.			E. end.	W. end.	E. end.	W. end.			

Experiment 111.—**To find the resistance of a coil by ammeter and voltmeter.**

Apparatus.—Voltmeter reading to $\frac{1}{20}$ th of a volt, ammeter reading to $\frac{1}{20}$ th of an ampere, cell or accumulator, plug key, the coil of which the resistance is to be found, wires, sand paper.

Method.—Arrange the apparatus as shown in the figure taking care that the + terminal of the ammeter is connected with the + pole of the cell and similarly the + and − terminals of the voltmeter are rightly connected. The voltmeter must be put in parallel with the coil and the ammeter in series with it. Before passing the current, find the value of the smallest division of the ammeter and the voltmeter and also see if there is any zero error in them. In case there is zero error and the pointer is adjustable, ask the teacher incharge to remove the zero error.

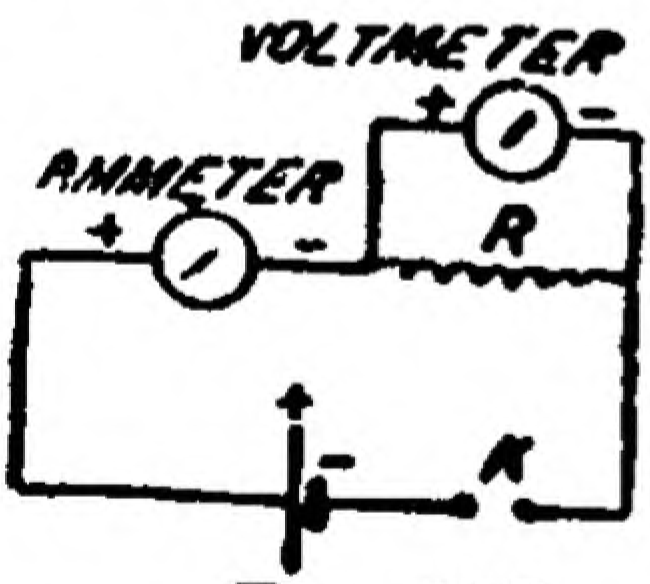


Fig. 185.

Pass the current by inserting the plug at K adjust the rheostat and note the deflections in the voltmeter and the ammeter. The ratio between the voltmeter and ammeter readings give the resistance of the coil. Take three observations by changing the rheostat contact.

Record your observations thus :

Zero correction of voltmeter=

Zero correction of ammeter=

No. of cells in circuit	Voltmeter reading E	Ammeter reading C	Resistance (Ohms) $R=\frac{E}{C}$

NOTE.—If the scales of voltmeter and ammeter permit, repeat the experiment with two coils in the circuit.

Exercises

(1) Find the resistances of an electric lamp or a bell.

(2) Compare the resistances of 250 cm. of No. 30 copper and german silver wires.

(3) Find the hot resistance of an electric bulb.

[*Hint.*—Use a voltmeter of range 250 volts in parallels with the circuit.]

(4) Prove the relation $\frac{1}{R}=\frac{1}{r_1}+\frac{1}{r_2}$ where r_1 and r_2 are two unknown resistances connected in parallel and R their equivalent resistance. (A voltmeter and an ammeter are provided.)

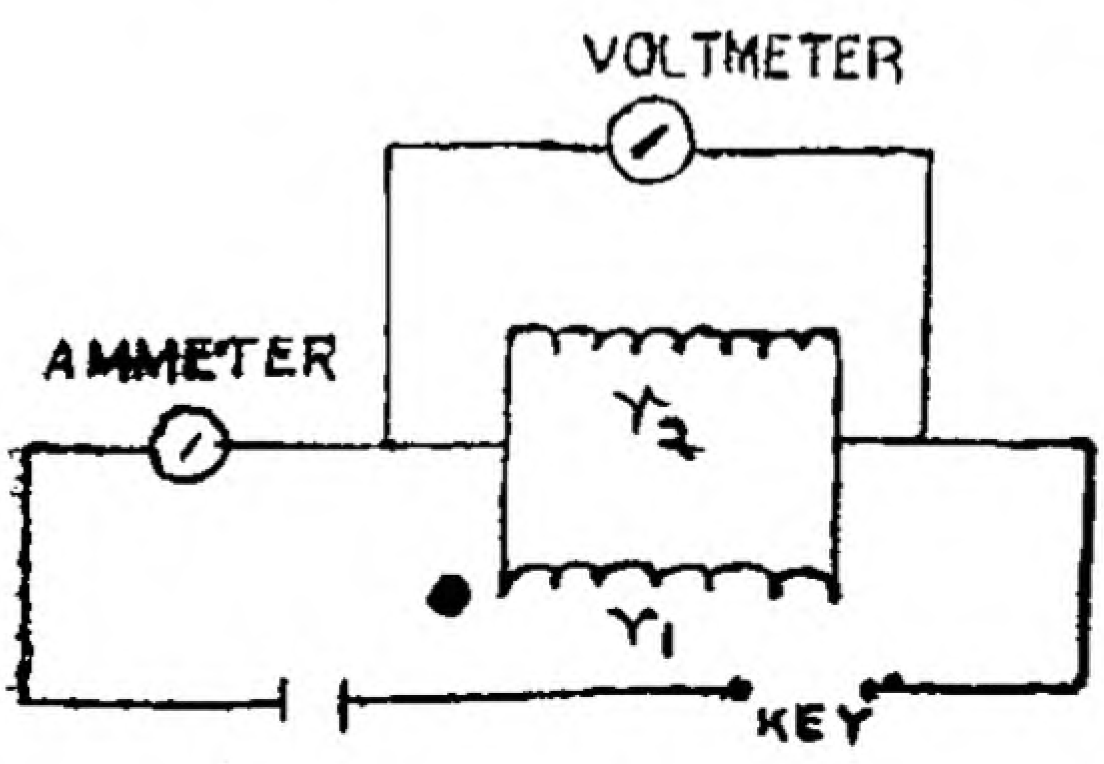


Fig. 186.

[*Hint.*—First find the values of the individual resistances r_1 and r_2 as described in experiment 111. Next connect them in parallel as shown in figure. Note the readings of the ammeter and voltmeter. Dividing the volt-

meter reading by the ammeter reading we get the equivalent resistance, show that this is equal to $\frac{r_1 r_2}{r_1+r_2}$. For taking more than one observation use a rheostat between the cell and the ammeter or the cell and the key.]

(5) Prove the relation $R=r_1+r_2$ where r_1 and r_2 are unknown resistances connected in series.

[*Hint* :—As in the last exercise first find the individual resistances r_1 and r_2 then connect them in series as shown in the figure 187.

Dividing voltmeter reading by ammeter reading calculate R and show that it is equal to r_1+r_2

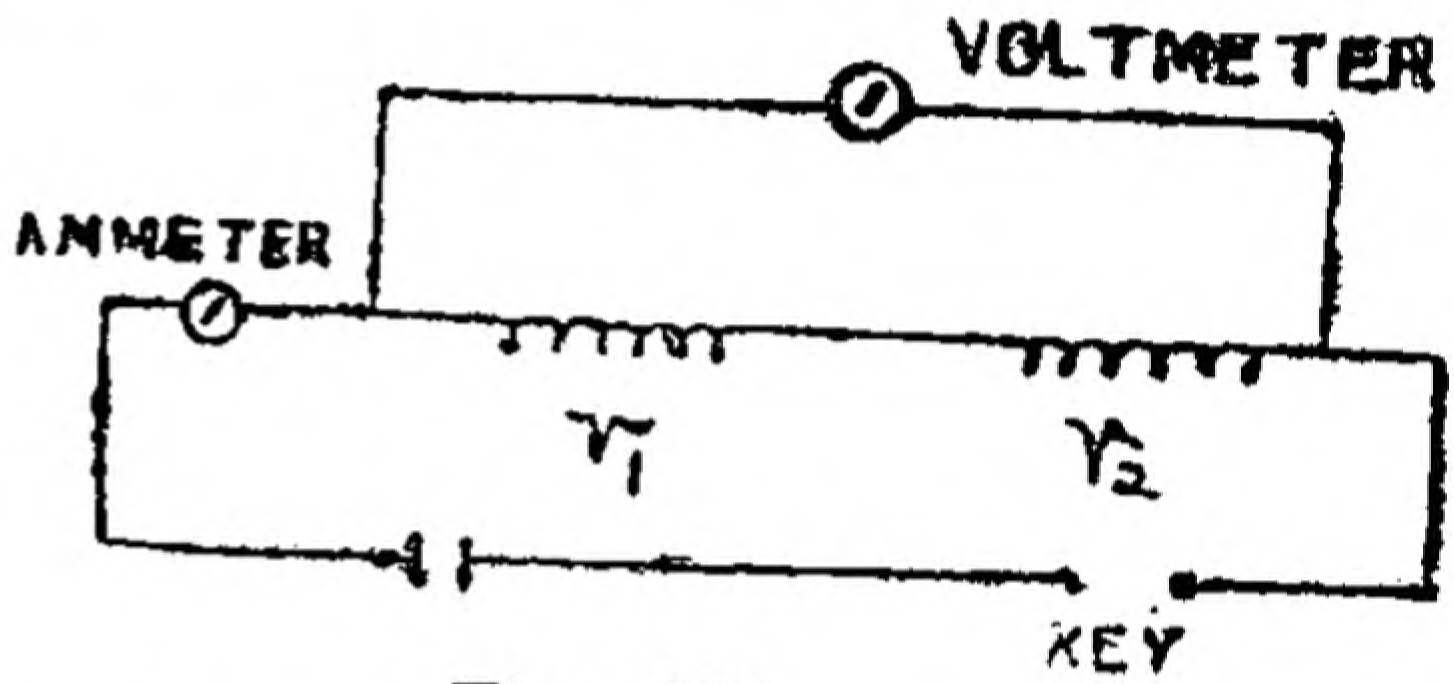
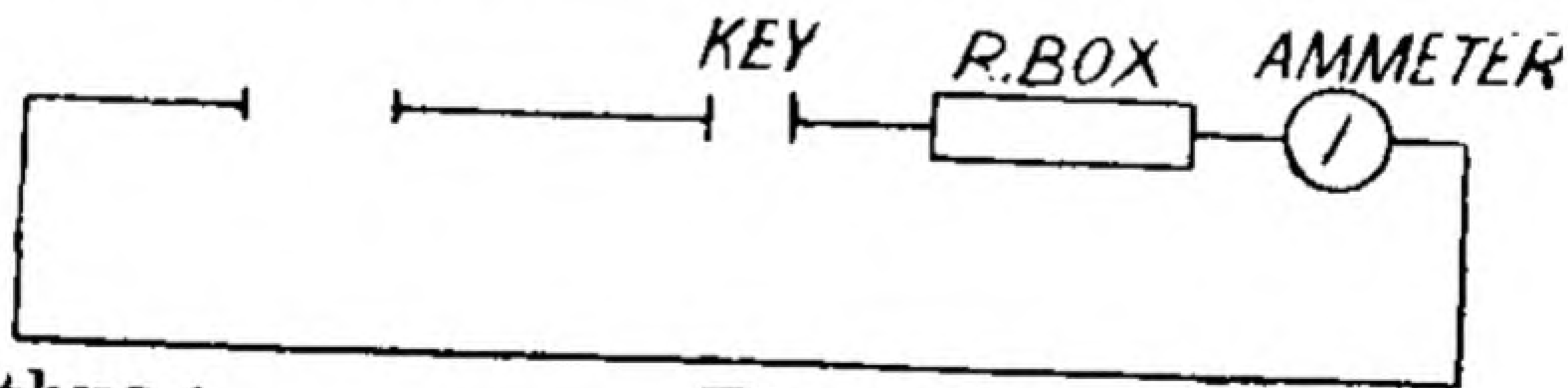


Fig. 187.

(6) Connect in series the given cell, a resistance box and an ammeter. Obtain a series of readings of the current C for different values of the resistance R in the box and tabulate. Plot a curve to show the relation between R and $\frac{1}{C}$.

[*Hint.*—Make connections as shown below.]



Tabulate thus :—

Fig. 188.

Zero correction of ammeter=

Resistance R	Ammeter reading	Corrected ammeter reading C	$\frac{1}{C}$

CHAPTER XXXVI

MEASUREMENT OF RESISTANCE BY WHEATSTONE BRIDGE

Resistances can be very conveniently compared by an arrangement known as *Wheatstone Bridge.* This consists of four resistances P, Q, R and S, which are arranged in the form of a quadrilateral. The ends A and C are joined to the two wires from a cell and the end B and D are joined through a sensitive galvanometer. The current which enters at A divides in two branches, one going along ABC and the other along ADC. There is a continuous fall of potential both along ABC and ADB, but we can so adjust the resistances P,Q,R, and S, that the potential at B is equal to potential at D. When the points B and D will be at the same potentials no current will flow in the galvanometer and it will show no deflection. In this condition, suppose the currents through P,Q,R and S are C_1, C_2, C_3 and C_4 and the potentials at A, B, C and D are V_a, V_b, V_c, and V_d.

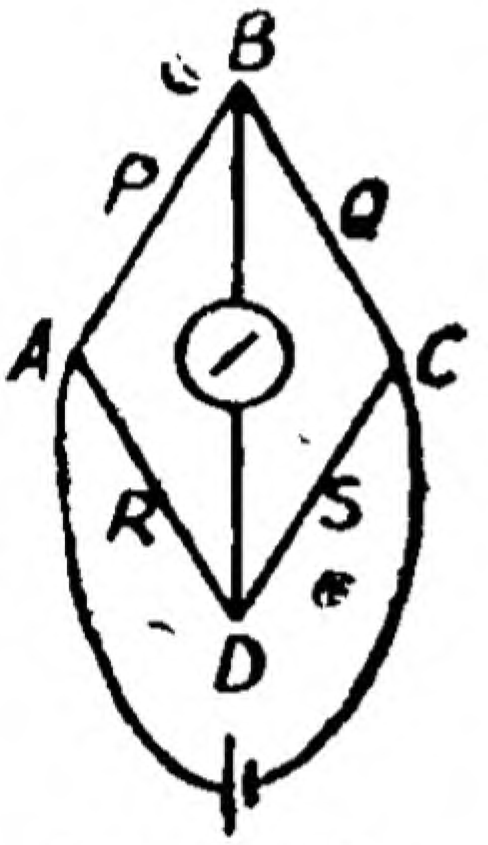


Fig. 189.

From Ohm's law we have

$$V_a - V_b = PC_1 \quad \ldots\ldots(1) \qquad V_a - V_d = RC_3 \quad \ldots\ldots(2)$$
$$V_b - V_c = QC_2 \quad \ldots\ldots(3) \qquad V_d - V_c = SC_4 \quad \ldots\ldots(4)$$

But as $V_b = V_d$

$$\therefore \quad PC_1 = RC_3 \qquad \text{and } QC_2 = SC_4$$

or

$$\frac{PC_1}{QC_2} = \frac{RC_3}{SC_4}$$

But as no current goes in the branch BD

$$\therefore \quad C_1 = C_2 \text{ and } C_3 = C_4 \text{ or } \frac{P}{Q} = \frac{R}{S}.$$

Measurement of resistances by the Wheatstone Bridge method is done either with the help of *Slide Wire Bridge* or the *Post Office Box.*

Slide wire bridge.—Fig. 190 represents a slide wire bridge. As the wire employed is generally one metre in length, it is also called a metre bridge.

It consists of one metre of uniform german silver or manganin wire, stretched along a metre scale and with its ends soldered to stout copper strips A and B of infinitesimal resistance. There is also another thick copper strip provided with terminals at H, C and K. Between the two gaps are placed the unknown resistance x and the resistance box R. The two terminals of a cell are connected to A and B through a key K..One end of a sensitive galvanometer is connected to C and the other to sliding contact or jockey, which moves over the wire. As resistances are proportional to lengths, the two parts of the wire *i.e.*, l_1 and l_2 form the ratio arms of the bridge.

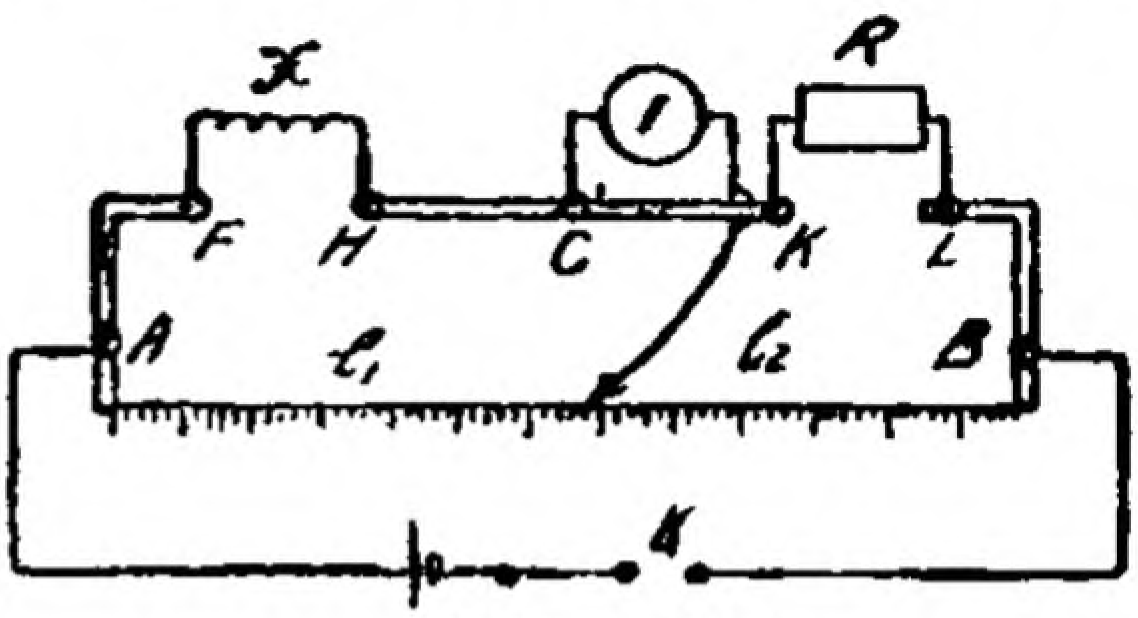


Fig. 190.

Experiment 112.—**Find the resistance of the given coil by the slide wire bridge.**

Apparatus.—Slide wire bridge, sensitive galvanometer (Weston pointer type). Leclanche cell and the coil.

Method. Connect the apparatus as shown in the figure 190, x is the given coil, **R** the resistance box. The key K must be inserted in the circuit so that the current may be cut off when the observations are not being taken. In this experiment we have to fix the position of a point on the wire by means of a jockey so as to give no current in the galvanometer.

To start the experiment, take out a plug from the resistance box, tighten the two plugs lying on the two sides of the plug removed. Note the direction in which the needle of the galvanometer moves when contact is made near one end of the wire and then near the other end. If the deflections are on opposite sides, the connections have been made correctly and you can proceed with the experiment. The balancing point will be between these two positions. If the

deflections are in the same direction in the two cases, then either the connection is somewhere faulty or that of the two resistances x and R, one is very much greater than the other. Change the resistance of **R** and check. To get good results, it is necessary that the resistances R and x should be of nearly the same magnitude *i.e.*, adjust the resistance R from the box and get the balancing point near the middle of the wire. Measure l_1 and l_2. Next increase R slightly and get new position of balance, then decrease R a little and find the third new position of balance.

For each position calculate separately the value of x

$$\frac{x}{R}=\frac{l_1}{l_2} \quad \text{or} \quad x=R\frac{l_1}{l_2}.$$

Record your observations thus :

Coil used No.........

Resistance taken out from the box	l_1	$l=(100-l_1)$	$x=R\frac{l_1}{l_2}$

Precautions :—1. Insert a key in the battery circuit.

2. Jockey should be pressed gently but firmly.

3. Do not keep the Jockey down longer than is absolutely necessary.

4. Balancing point should be got near the middle. If the ratio between the two parts is more than 3 : 2, change R.

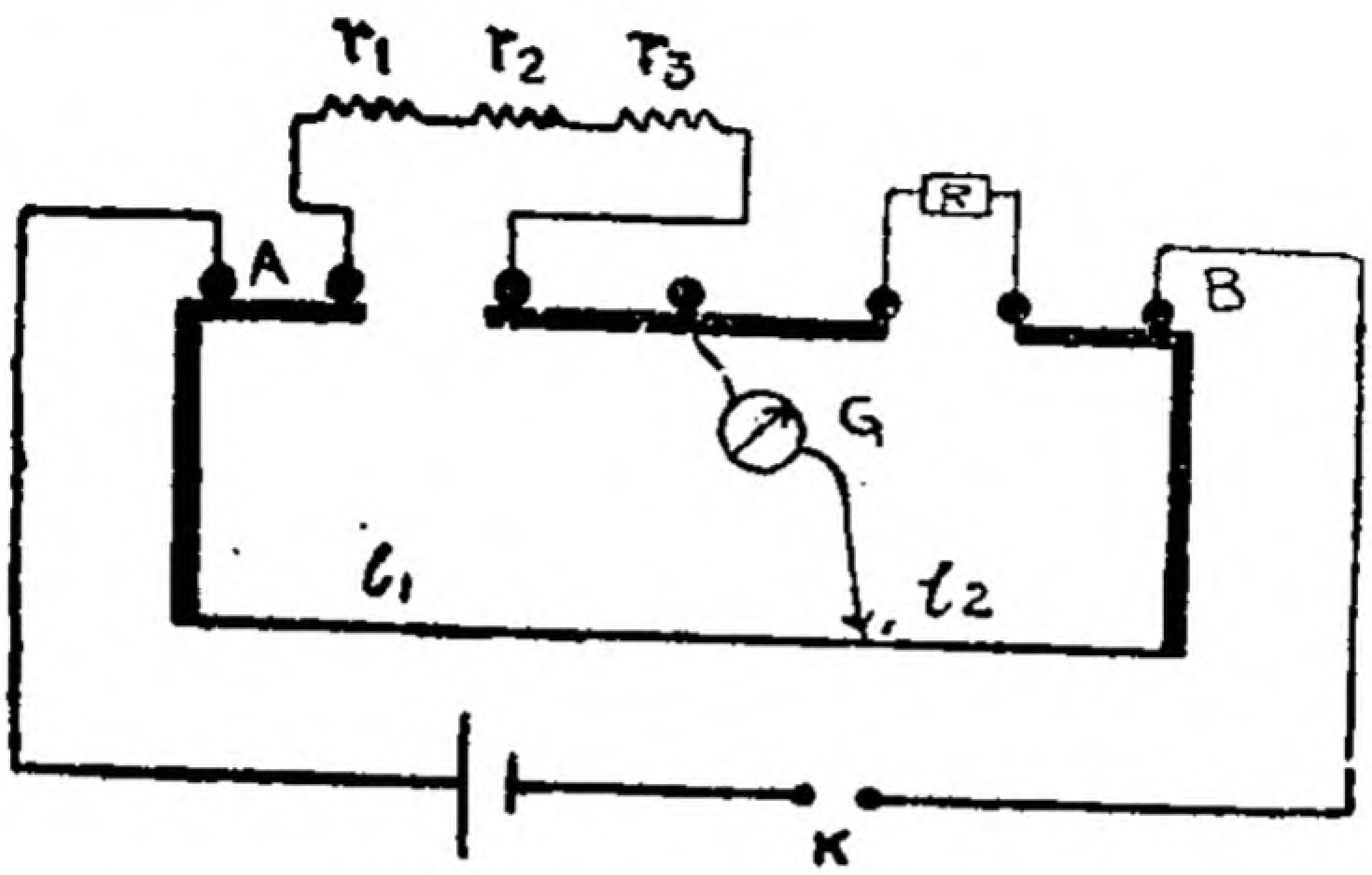
5. Wire of the metre bridge should be cleaned.

Experiment 113.—**Prove the laws of resistances in series and in parallels.**

Apparatus.—Three different coils and the same apparatus as given in experiment 112.

First find the resistances of the coils separately with a slide wire bridge as described in experiment 112. Let the resistances be r_1, r_3 and r_2 ohms.

Find the sum of r_1, r_2 and r_3.



(Series arrangement)

Fig. 191

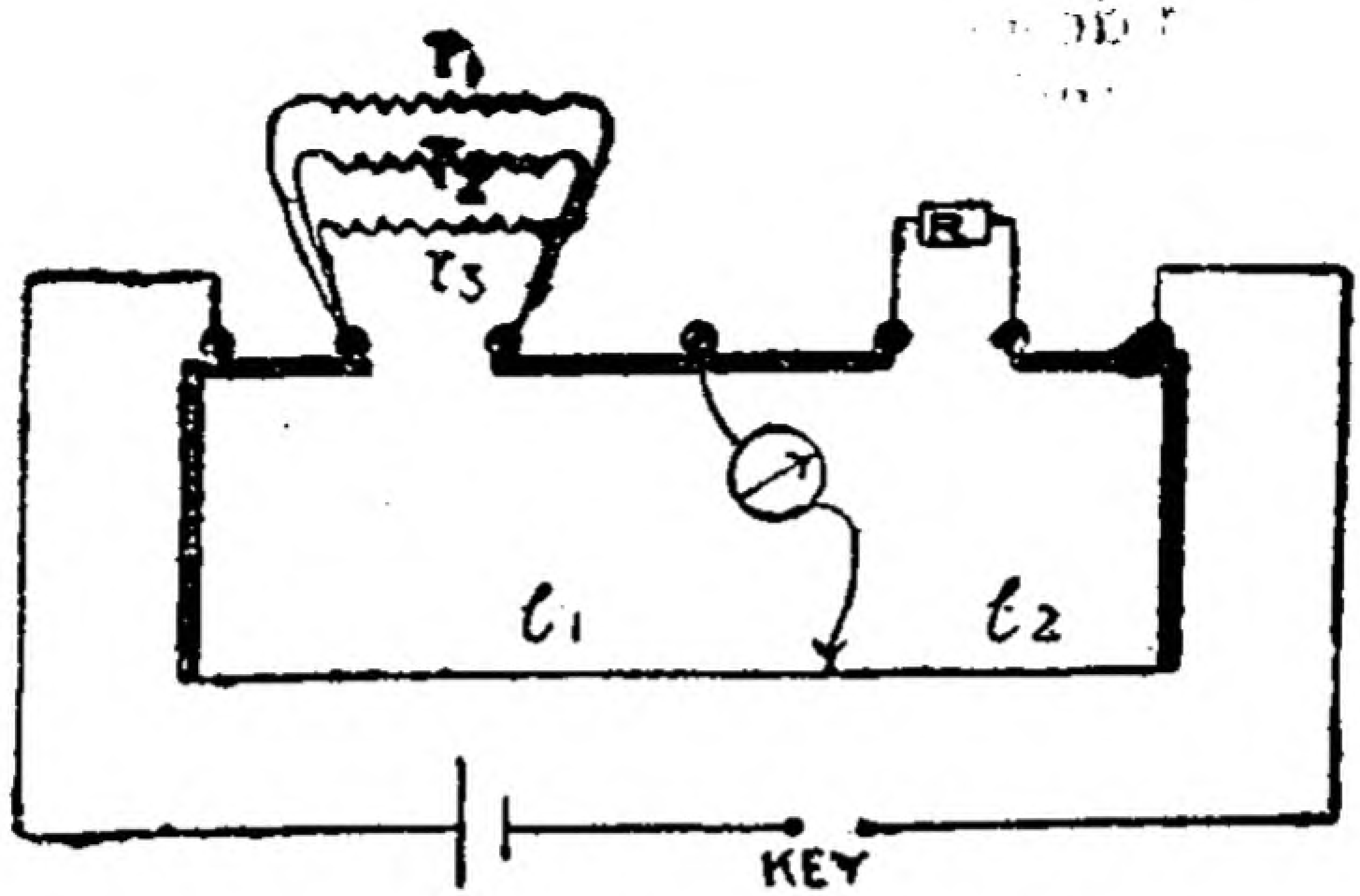
Next join the resistances r_1. r_2, r_3 in series as shown in the figure. Adjust the resistance R in the resistance box so that the balancing point is nearly in the middle ; note the lengths l_1 and l_2. Repeat the experiment a number of times by changing R in the resistance box.

Calculate the joint resistance x.

Record your observations thus :—

No. of observations	Resistance taken out from the box R	l_1 cms.	$l_2=(100-l_1)$ cms.	$x=R\frac{l_1}{l_2}$
(1)				
(2)				
(3)				Mean $x=$

Verify that x is equal to $r_1+r_2+r_3$.



(Parallel arrangement)

Fig. 192

Connect the coils in parallels as shown in Fig. 192. By taking out suitable plugs from the resistance box, adjust R so that the balancing point lies near the middle of the wire. Repeat the experiment by suitably changing R. Calculate the equivalent resistance S.

Record thus :—

No. of observations	Resistance taken from the box R	l_1 cms.	$l_2=(100-l_1)$ cms	$S=R\dfrac{l_1}{l_2}$
(1)				
(2)				
(3)				Mean S=

Now $\dfrac{1}{r_1}+\dfrac{1}{r_2}+\dfrac{1}{r_3}=\dfrac{r_2r_3+r_1r_3+r_1r_2}{r_1r_2r_3}$

Verify that $S=\dfrac{r_2r_3+r_1r_3+r_1r_2}{r_1r_2r_3}$.

NOTE. Instead of using three coils use only two.

Precautions :—Same as in experiment 112.

Exercise (1). Show that the resistance of a wire is proportional to its length.

[*Hints.*—Find the resistance of 3 pieces of wire cut from the same long piece, but in length 50, 100, 150 cms. respectively. To get exact length between the binding terminals, cut each wire 1 cm. longer than given above. Bare both the ends upto 0·5 cm. and bend the bared ends to a right angle. Place the bared ends in each of the two binding screws taking care that the wire leaves the binding screws just where the bend is situated. The portion of the wire in the binding screw will not offer any resistance. Connections are to be made as in the last experiment.

Exercise (2). Given a manganin wire, what length of this wire will be required to make a one Ohm coil ?

Specific resistance.—The resistance of a wire 1 cm. long and having an area of cross section 1 sq. cm. is called the specific resistance of the material of the wire. Resistance of a wire is directly proportional to its length, inversely proportional to its area of cross section,

i. e., $$R \propto \frac{l}{a} \text{ or } R = \frac{Kl}{a},$$

where K is a constant depending on the nature of the material of the wire. It is called the *specific resistance* or the *resistivity* of the material.

Experiment 114.—**To find the specific resistance of a given piece of wire.**

Apparatus.—Same as in experiment 112 but instead of a coil use a wire of german silver or of some other alloy 101 cms. in length.

Method.—Proceed exactly as in experiment 112 and find the resistance of the wire. While connecting 0·5 cm. of wire under each of the binding screws as described already. The effective length of the wire will thus be 100 cm. Bare the wire at a number of points and measure the diameter at least at 10 different places by means of a screw gauge and calculate the mean value of r and from that the value of a the area of cross-section, using the formula $a = \pi r^2$.

Stretch the wire along a scale and measure its length, allowing for the length under the binding screws.

$$R = K\frac{l}{a}$$

where R=resistance, l=length of the wire ; a=area of cross-section.

i.e., $K = \frac{Ra}{l}$.

Express the result as......10^{-6}.

For recording observations for the measurement of the resistance R, use the same table as in the last experiment. Record the other observations thus :

Zero correction in the micrometer screw gauge=

Diameter of the wire ..(1)...(2)....(3) ..(4) ......(5)......(6) ......(7).........(8).........(9).........(10).......Corrected mean r=

Metal used	Length l	Cross-section πr^2	Resistance R	$K = \frac{R\pi r^2}{l}$

Precautions.—At least 10 readings should be taken for the diameter at different places. Other precautions are same as in experiment 112.

Question.—Why should we take so many as 10 readings for the diameter ?

Post office box.—This is a more compact form of the Wheatstone Bridge and a resistance can be measured by it more accurately than by a metre bridge.

We have seen that when the bridge is balanced $\frac{P}{Q} = \frac{R}{S}$.

Thus when R and the ratio $\frac{P}{Q}$ are known, S can be found at once.

In a Post office box, we have a number of resistance

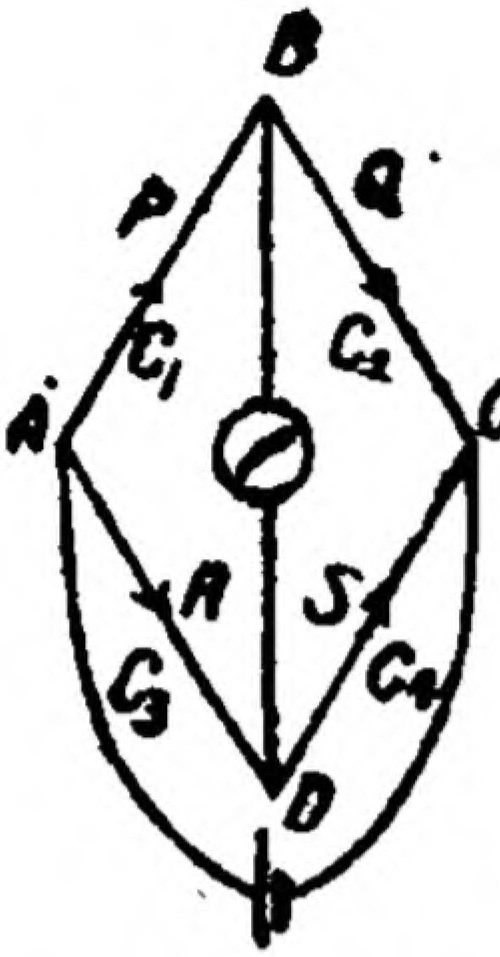


Fig. 193 A.

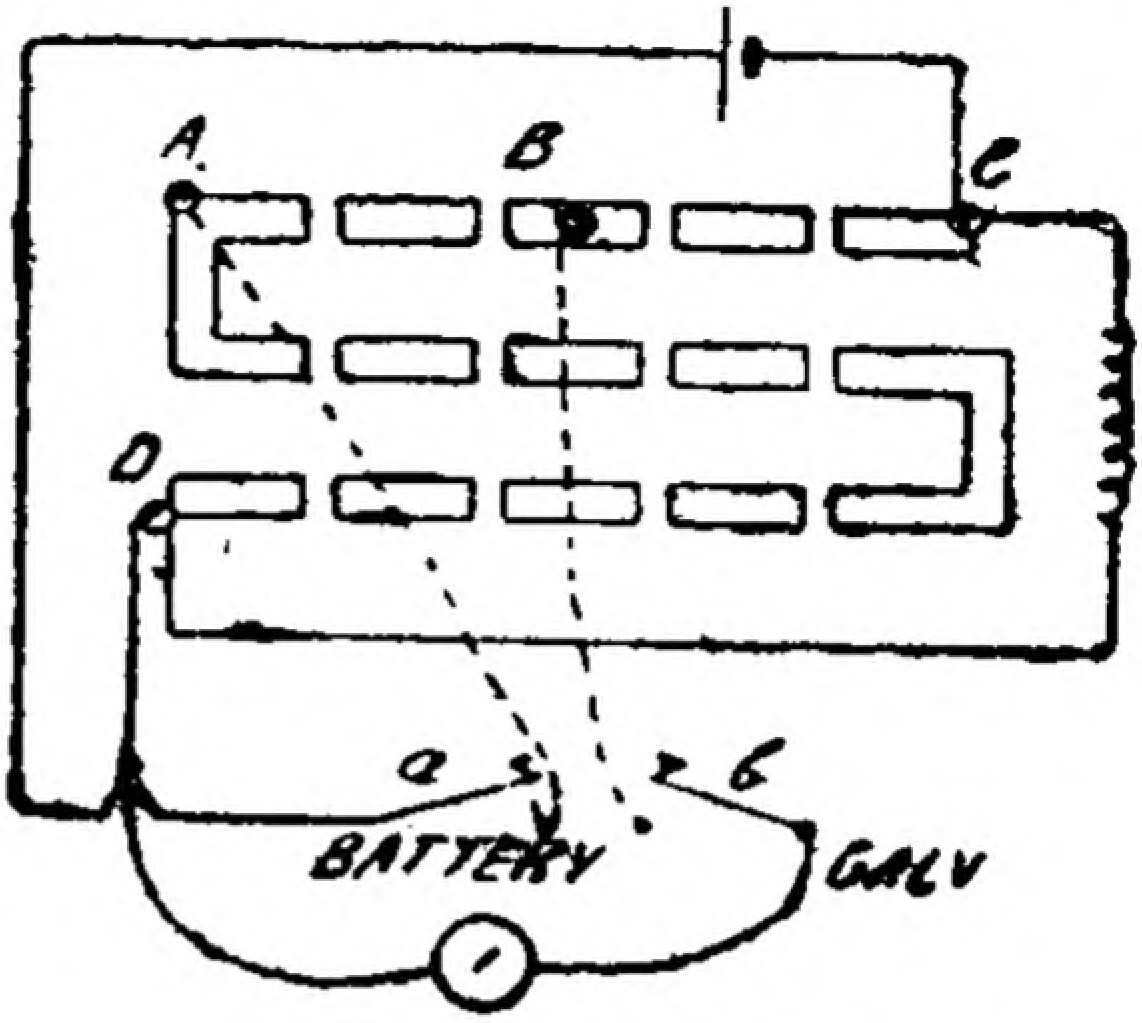


Fig. 193 B.

coils arranged so as to form the arms P, Q, R and S of Fig. 193 A. Corresponding points in Fig. 193 A and 193 B are lettered similarly. The arms AB and BC (P and Q) are called the ratio arms and each of these generally consits of three coils of 10, 100 and 1000 Ohms. The third arm AD, *i.e.*, R consists generally of a number of coils ranging from 1 to 4000 Ohms. A thick wire passing under the ebonite cover of the box connects A to the stud of the key (*a*) and similarly the point B is connected with the stud of the key (*b*). White lines drawn on the cover of the box show permanent connections. The resistance S to be measured is connected between C and D. The battery terminals are connected to C and *a* and the galvanometer to *b* and D.

The actual arrangement of resistances in a Post office box differs in different patterns. The students will not find any difficulty in identifying the ratio arms and the adjustable arm. The top of the box is marked generally with cryptic letters C, Z, E, L, G, sometimes for C and Z only B is used. These denote carbon, zinc, earth, line and galvanometer respectively. B stands for battery. The unknown resistance is connected between E and L, battery between C and Z and galvanometer to G and G. The apparatus of course can be connected with the help of these letters but the student should always draw his own standard diagram as in Fig. 193 and connect up the parts.

It should be noted that the positions of the battery and galvanometer can be interchanged without affecting the result in any way, *i.e.*, the battery can be connected to B and D and galvanometer to A and C.

While using a Post office box, the plugs when removed, should be put in the lid of the box and not on the table and care should be taken not to mix the plugs of one box with those of another.

Experiment 115.—**To find the resistance of the given coil by Post office box.**

Apparatus.—Post Office box, Leclanche cell, sensitive galvanometer (Westen Type), connecting wires and the coil of which the resistance is to be found.

Method.—Connect up the apparatus as shown in previous diagrams. Draw the standard diagram of the Wheatstone bridge and check your connections. The unknown resistance is to be connected between C and D, *i.e.*, the terminals marked L and E by the manufacturers. Before performing the experiment, press firmly with slight twisting motion every plug and see that all of them are tight and no screw where a wire has been joined is loose.

Now remove the plugs marked 10 in each of the ratio arms and with no key out from the arm R, *press first the battery key* and then the galvanometer key, see the direction in which the needle of the galvanometer is deflected. Next take out the plug marked 'infinity' and again depress the keys. If all the connections are correct, the deflection will be on the opposite side. If not check your connections and tighten the plugs and see that you get the deflection in the opposite direction. Replace the infinity plug and take out the plug corresponding to any 1000 Ohms and observe the direction of deflection. If the deflection is in the same direction as it was with infinity plug, the resistance 1000 is too large. Try the next lower plug and so on till you find that the direction with plugs differing by unity (say 54 and 55) is in opposite directions. This means that the unknown resistance S is between 54 and 55 Ohms.

Next make the ratio arms as 100 : 10, when the 100 Ohm plug is taken out, the 10 Ohm plug of that arm should

be ıt back in its position. 100 Ohm plug should be taken outfrom the arm in continuation of which there is the adjstable arm R. In the diagram it should be taken out fro the arm AB. Adjust the resistance R, till approxima balance is obtained. In this case R is to lie between 54(and 550 Ohms. Find the two resistances differing by uny which will give deflections in opposite directions. Supose these are 547 and 548. The resistance S is therefor between 54·7 and 54·8 Ohms.

Next remove the plug from 1000 Ohm coil and insert th plug in 100 Ohm coil. The ratio of the arms P and Q is ıow 100 : 1. R is now to lie between 5470 and 5480. Fid out the two resistances differing by unity which will gie deflections in opposite direction.

Record your observations thus :

Coil used.........

Iatio arm P	Ratio arm Q	$\frac{P}{Q}$	R (Ohms)	S

Precautions.—1. See that all the plugs are fitting tightly in their holes.

2. Insert and r plugs with a slight screwing motion.

3. When any plug is removed, tighten the two plugs lying on its two sides. Press the keys momentarily. To decrease the effect of self induction, battery key should be pressed first and then the galvanometer key.

CHAPTER XXXVII

COMPARISON OF ELECTROMOTIVE FORCES OF CELLS

Electromotive force.—Electromotive force of a cel is the force driving electricity through the whole of the ciruit of a cell. It is written as E. M. F. It may be *supposed* at one portion of it drives the current through the extenal circuit and the other through the liquid of the cell. he former is called the Potential Difference (P. D.) between he plates. When the current is flowing, the P. D. will be ss than the E. M. F. because some force is spent in driving he current through the liquid of the cell. Thus the distincton between E. M. F. and the P. D. between the terminals of cell is that the former is the total difference of potential cting round the whole circuit including the liquid, whilst te latter is the difference of potential between the positive and the negative plates of the cell.

Thus on open circuit, *i. e.*, when the current is not flowing, the E. M. F.=P. D. between the plates It is not possible to measure the E. M. F. directly, we can measure it in terms of potential difference it creates at the terminals on open circuit.

Fall of potential along a wire carrying current :—When a current flows through a wire of uniform area of cross section, there is a continuous fall of potential along it. Thus if A, B, C, D and E are the points on a conductor, the difference of potential between A and B is greater than that between B and E or C and E.

Experiment 116.—**Using a Voltmeter, show that the fall of potential between two points on a uniform wire carrying current is proportional to its di[illegible] between them.**

Apparatus.—Voltmeter reading to ·05 of a volt; jockey or knife edge, plug key, 2—4 volt battery, wire board having one metre of a thin resistance wire of manganin, platinoid or German Silver stretched on it along a scale with two terminals at the end.

Method.—Connect one end of the voltmeter (+) to the terminal of the wire near the zero division of the scale and to this end connect also the + pole of the battery. Join the other end of the voltmeter to the knife edge. The negative pole of the battery should be connected through the key K to the other terminal on the wire board.

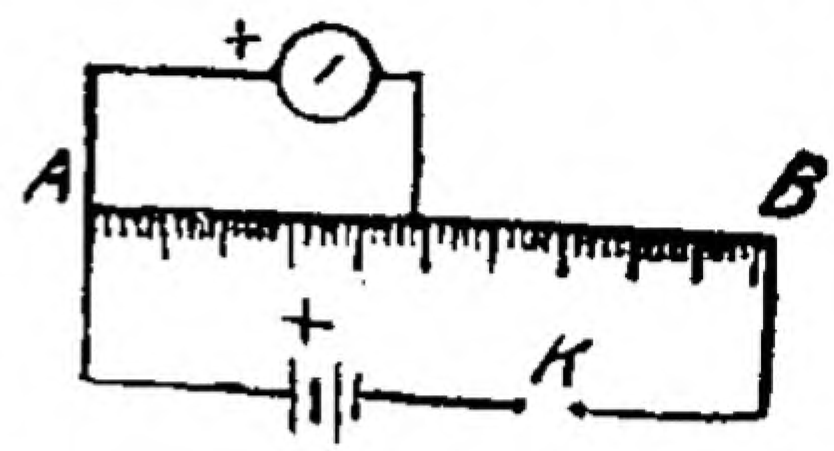


Fig. 194.

Note the zero error in the voltmeter if any. Place the knife edge on the wire opposite the 20th cm. mark and note the reading on the voltmeter. Knife edge should press on the wire gently. Remove the plug from the key when you are recording observation in your note book. Next take observations opposite 30, 40, 50, 60, 70, 80 cms. marks for the forward motion and also at the same points for the backward motion. Take mean of the deflection at each point. *Plot a curve between l (abscissae) and θ (ordinate).*

Record your observations thus :

Zero reading of voltmeter=

Correction factor=

Length of wire (l)	Voltmeter reading		Corrected voltmeter reading		Mean	Volt per cm., V/L
	Forward motion	Backward motion	Forward motion	Backward motion		

Mean fall of potential per cm. of wire=

∴ Fall of potential for any length l=

NOTE :—(1) If accumulators are used as source of current there is no necessity of taking observations for the backward motion. In this case wire should have sufficient resistance, or

better, an additional resistance may be introduced in the circuit.

(2) If deflections obtained are small, a board having 4 to 5 metres of wire stretched on it may be used. In this case the first reading should be taken at about 250 cm.

Precautions.—1. Pass the current for just as much time as is necessary for taking a reading.

2 Press the knife edge gently and keep the contact steady.

3. Wire of the wire board should be cleaned.

Second method by using tangent galvanometers. Connect the apparatus as shown in the Fig. 195. AB is the wire stretched on the wire board.

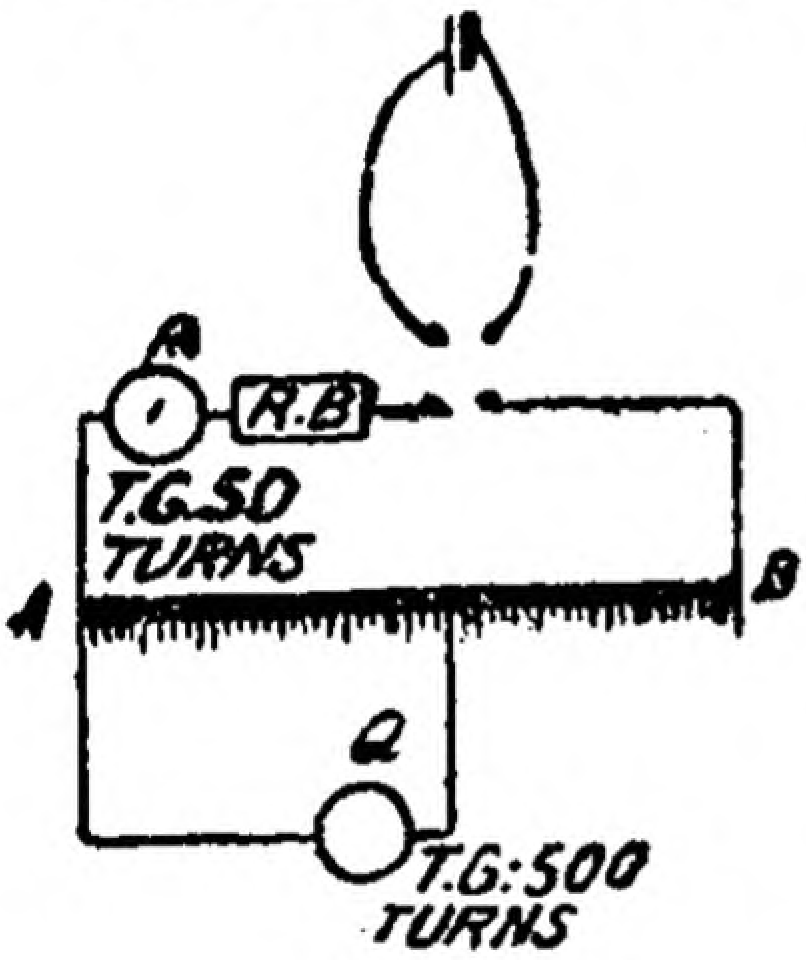


Fig. 195.

50 turn coil of the galvanometer P should be connected and 500 turn coil of the galvanometer Q. A commutator is to be used as shown in the figure 195.

The galvanometer Q (high resistance) will serve as voltmeter ; one end of it should be connected to A and the other end to a knife edge which can move along the wire. Set the two tangent galvanometers. Place the knife edge on the wire opposite the 20 cm. mark, note the deflection of both ends of the pointer of the galvanometer Q. Reverse the current and again note the deflection. Move the knife edge to 40, 60, 80, and 100 cm. marks and note the deflections (forward motion) both for direct and reversed current. Repeat the observations at the same marks for backward motion also. If the deflection be very large a small resistance should remain constant throughout the experiment. Find mean value of the deflection for each position and find the ratio between the tangent of the angle and the corresponding length. Note also the deflection of the galvanometer P both at the beginning and the end of the experiment. It is used to show if the current remains constant during the experiment.

Record your observations thus :

Deflection of the galvanometer P at the beginning=

Deflection of the galvanometer P at the end =

Length of the wire	Deflection of galvanometer Q				Mean θ	$\tan\theta$	$\frac{\tan\theta}{\text{Length}}$
	Direct current		Reversed current				
	E. end	W. end	E. end	W. end			

Precautions.—1. Same as in the last experiment.

2. The deflection of the galvanometer P should remain constant, if it has changed, it means that the current has not remained constant during the experiment.

Potentiometer :—It is an apparatus used for comparing E. M. F. of cells. It consists of a long stretched manganin or platinoid wire of four metres or more in length and having a uniform area of cross section. The wire is placed along metre scales on wire board and is arranged in zigzag fashion to economise space. It is also provided with a sliding contact or jockey so that the contact can be made at any point on the wire. For considering the theory of the method, it will be simpler to consider the wire to be 1 metre in length, as shown in the Fig. 196.

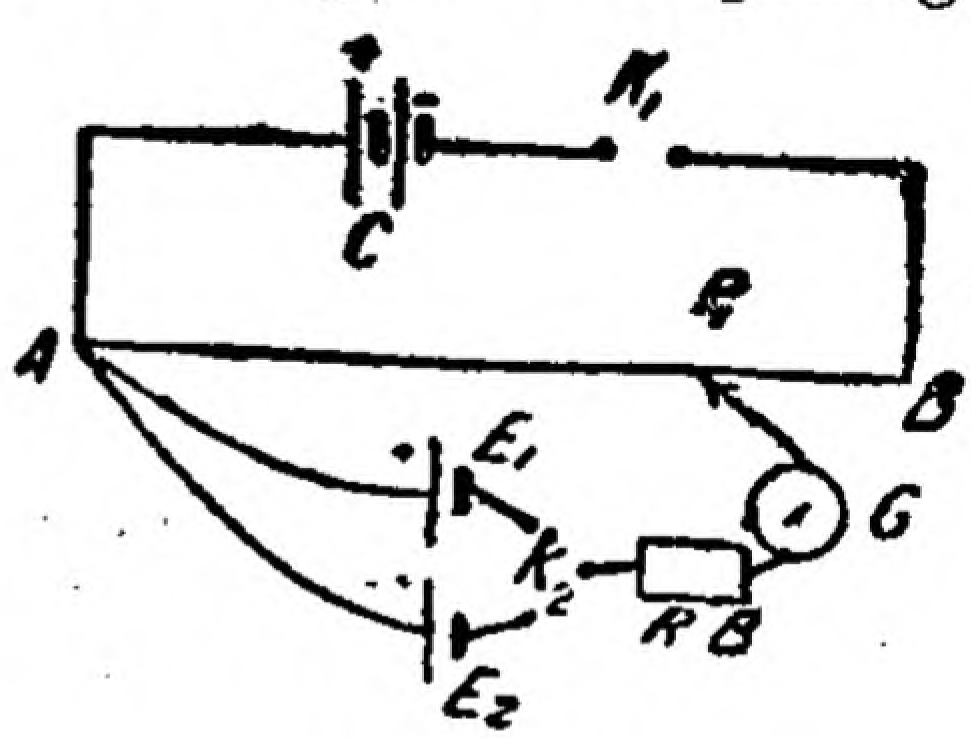


Fig. 196.

A constant battery C consisting of one or two accumulators is connected to the points A and B through a plug key K. The positive pole is connected to A. E_1 and E_2 are two cells of which the E. M. F's are to be compared. The positive pole of each of these also is connected to A, the negative poles are connected to a two way key, a resistance box, a sensitive galvanometer (Weston) and a sliding contact as shown in the figure.

When the current from the battery C is passed, there is a regular fall of potential along the wire from A to B. Now pass the current also from E_1 while current from C is passing and move the sliding contact forward and backward and find a point P_1 on the wire which gives no deflection in the galvanometer. As there is no current in the galvanometer, it means that the point P_1 and the pole of the cell connected to the galvanometer are at the same potential, *i.e.*, the fall of the potential through the cell E_1 is equal to the fall of potential between the points A and P_1 on the wire. As no current is passing through the cell E_1 therefore the difference of potential between its terminals is equal to its E. M. F. Thus the E. M. F. of E_1 is exactly equal to the difference of potential between A and P_1 and as the wire is of uniform area of cross section, this potential difference is proportional to the length AP_1 of the wire.

The cell E_1 is then put out of circuit and with the cell E_2 in circuit, a point P_2 is found in the same way such that the E. M. F. of E_2 is proportional to the length AP_2.

We have thus

$$\frac{E_1}{E_2}=\frac{AP_1}{AP_2}=\frac{l_1}{l_2}.$$

Experiment 117.—**To compare the E. M. F's of two cells by potentiometer method.**

Apparatus.—Potentiometer, one or two accumulators, two cells (Leclanche and Daniel) resistance box, Weston or some other sensitive galvanometer, one plug key, one two way key, connecting wires, jockey etc.

Method.—Make the connections as shown in the last figure, taking care that all the positives of the three cells are connected at the same point A. Plug key in the accumulator circuit must be introduced. The two key, resistance box and galvanometer should be connected as shown. Take out some resistance, say 200 Ohms from the box, insert the

plug in the key K_1 and pass current from the cell E_1 also. Put the sliding contact first near one end of the wire and then near the other end and see whether the deflections of the needle are in opposite directions for your connections are correct and you can proceed on with the experiment ; if not, either your connections are faulty or the E. M. F. of the accumulator is less than that of E_1.

Move the sliding contact on the wire and find a point on the wire which gives no current in the galvanometer. This will give roughly the position of the balancing point. Now put back the plug taken out from the resistance box, *i.e.*, with zero resistance from the box find accurately the position of the balancing point P_1 and read the length AP_1. Next change the position of the plug in the two way key and have the cell E_2 in the circuit and find the position of the point P_2 so that there is no current in the galvanometer. Read the length AP_2.

Once again take a reading for the first cell E_1 and use mean value in the calculations.

Repeat the experiment and calculate results separately.

Record your observations thus :—

Standard cell used :—

No. of observation.	Balancing point for E_1	Balancing point for E_2	$\frac{E_1}{E_2}=\frac{l_1}{l_2}$

Mean of $\frac{E_1}{E_2}=$

Pre cautions.—1. Clean the wires of the potentiometer. Use Brasso rather than sand paper.

2. Clean with sand paper the ends of the connecting wires.

3. See that all the + terminals of the cells are at one point.

4. Insert a key in the accumulator circuit.

5. Do not pass current for a long time.

Experiment 118.—**Comparison of E. M. F's. of two cells using a moving coil pointer type galvanometer.**

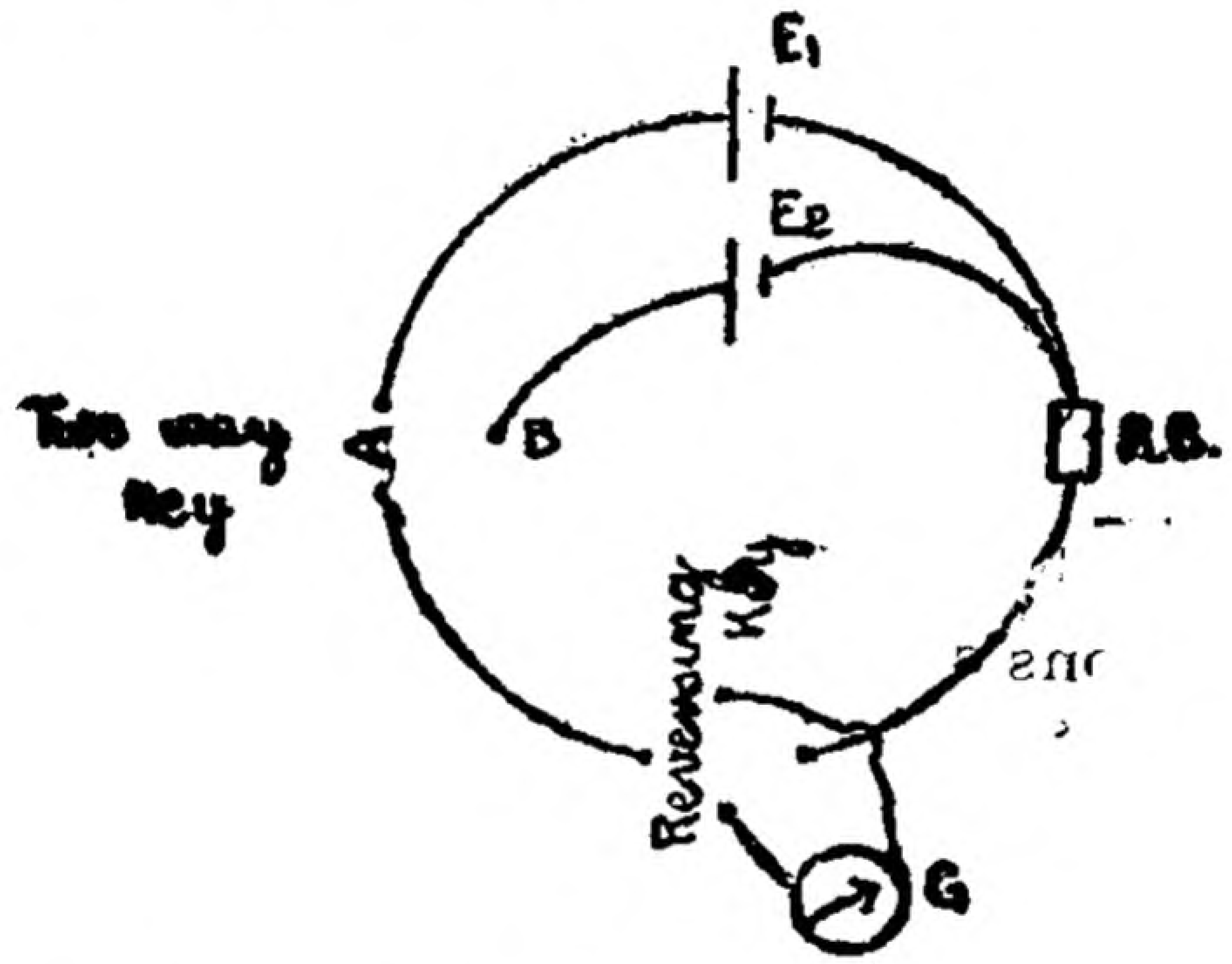


Fig. 197.

Apparatus :—Two cells, resistance box, two way key, galvanometer (Weston) or some other sensitive type and a reversing key.

Method.—Arrange the apparatus as shown in the figure. Put the plug in the position A when the cell E_1 will be in circuit and take out *a fairly high resistance*, about 3000 ohms, from the resistance box so that the deflection in the galvanometer is about 15 to 18 divisions. Note the deflection θ_1'. Then reverse the current in the galvanometer and note θ_1''. Get the mean of the two observations and call it θ_1. Next with the same resistance change the plug to the position B and note deflections as before and get θ_2 when the cell E_2 is in circuit.

Take two more independent observations, with different resistances in the circuit. Use of the reversing key is not essential in this experiment.

Calculate $\frac{E_1}{E_2}=\frac{\theta_1}{\theta_2}$ for each of the observations and take mean.

Tabulate your observations as shown below.

No. of obs.	Resistance taken out	Cell E_1			Cell E_2			
		Direct	Reverse	Mean θ_1	Direct	Reverse	Mean θ_2	$\frac{E_1}{E_2}=\frac{\theta_1}{\theta_2}$
1								
2								
3								
4								

Precautions. Clean the ends of wires.

2. Connectic should be tight.
3. Do not pass a heavy current.
4. Insert a *high resistance* in the circuit.
5. Do not pass the current for a long time.

NOTE.—For independent observations, experiment should be repeated with different resistances.

Experiment 119.—**Comparison of E. M. F's. of two cells by sum and difference method using a sensitive galvanometer (Weston type).**

When cells are helping each other *i.e.*, for (E_1+E_2) make connection as shown in the figure. Put the cells in series *i.e.*, connect the + terminal of the one with the —tive of the other, Take out a high resistance from the resistance box and note the deflection

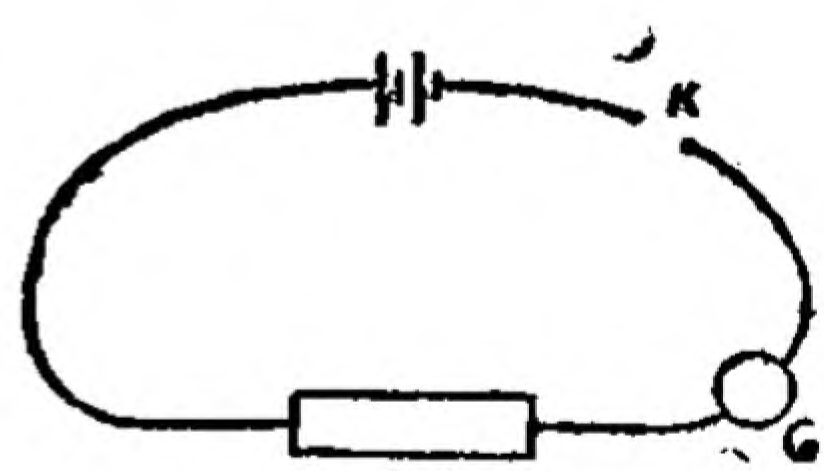


Fig. 199.
Cells helping

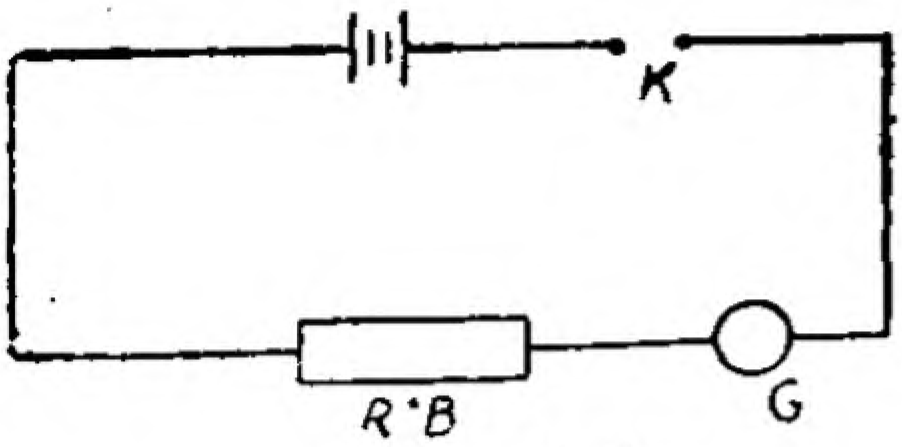


Fig. 199.

Cells in opposition

θ_1. Next put the cells in opposition *i.e.*, for (E_1—E_2) join the two negative terminals or the two positives together and with the same resistance in circuit note the deflection θ_2.

$$\frac{E_1}{E_2}=\frac{\theta_1+\theta_2}{\theta_1-\theta_2}.$$

Change the resistance and take two more independent observations.

NOTE.—*Resistance taken out should not be so high that the deflection becomes very small when cells are in opposition.*

Tabulate your observations thus :—

Resistance taken out	Cells helping Deflection θ_1	Cells in opposition Deflection θ_2	$\frac{E_1}{E_2}=\frac{\theta_1+\theta_2}{\theta_1-\theta_2}$
(1)			
(2)			
(3)			

$$\text{Mean}\ \frac{E_1}{E_2} =$$